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FINAL REPORT

INTEGRATED MANAGEMENT OF DISEASE, INSECT AND WEED PESTS IN ALTERNATIVE CROP PRODUCTION SYSTEMS FOR SASKATCHEWAN

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Integrated Management of Disease, Insect and Weed Pests in Alternative Crop Production Systems

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Final Report

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Alternative Cropping Systems

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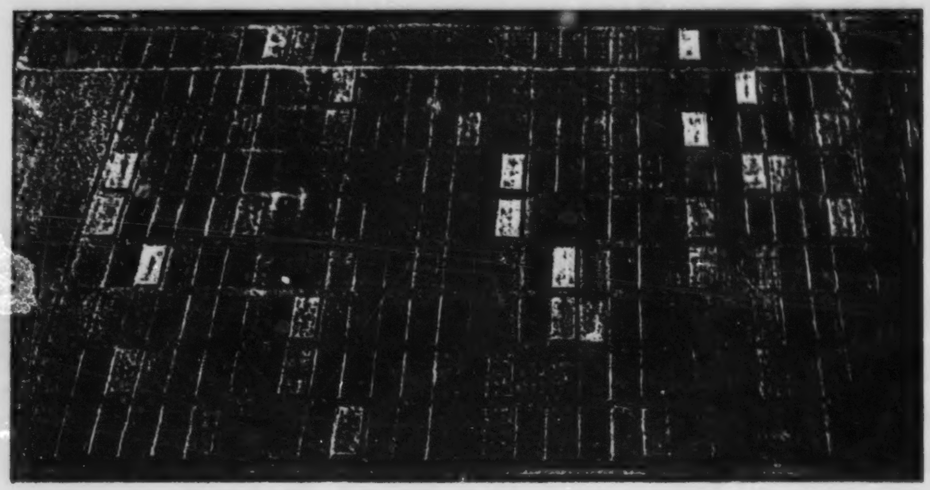
Prairie Ecozone

Research Farm
Scott, Saskatchewan

Scott Alternative Cropping Systems Project Review: The First Six Years



April 4 and 5, 2001
Saskatoon, Saskatchewan

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Scott Alternative Cropping Systems Project Review: The First Six Years

Edited by

A. Gordon Thomas and Stewart A. Brandt

Alternative Cropping Systems Project
Volume 9 - Workshop Proceedings
Agriculture and Agri-Food Canada, Saskatoon Research Centre
107 Science Place, Saskatoon, Saskatchewan, S7N 0X2

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Preface and Acknowledgements

A workshop was held in Saskatoon on April 4 and 5, 2001. The goal of the workshop was to give project participants and others interested in cropping system research an opportunity to informally discuss, review and plan the research activities of the Scott Alternative Cropping System Project and to explore ways of using the project as a learning centre for research, education and technology transfer. In addition to the project research team, cropping system researchers from Western Canada, representatives from granting agencies, and extension specialists were invited to participate. Many of those invited had toured the site and had asked to be included in any workshop activity. Others wanted to know more about the project and to explore the possibility of some collaborative research. Also, the workshop was an opportunity for the invited participants to learn about organizing, establishing and operating long-term multidisciplinary cropping system projects. The comments and constructive criticism from all the participants were very much appreciated by the members of the project team.

The workshop was organized into five sessions. The opening session was used to familiarize participants with the workshop organization, objectives and expectations and to describe the experimental design and cropping systems that had been implemented in 1995. In the second session, each member of the multidisciplinary research team summarized and reviewed the information they had collected annually in the nine cropping systems during the first 6-year rotation cycle. Thirteen presenters described their results and major accomplishments in the areas of crop production, economics, energy, agricultural meteorology, fertility, erosion risk, biodiversity of soil biota, insect pests, diseases and weeds. The third session focussed on completed and planned sampling that only occurred between the end of the first cycle in the fall of 2000 and the beginning of the second cycle in the spring of 2001. Four presenters described their research on soil quality. Other end-of-cycle activities were highlighted in a general discussion. The next session explored ways to use the contributions of the separate disciplines to address interdisciplinary issues. A key element in the success of any interdisciplinary endeavour is the sharing of data and results among project participants and sharing accomplishments with a wider audience. A framework for achieving this objective was discussed in one paper. Data from the 1994 site characterization year were used to examine the spatial relationships of various soil, topographic and site history factors with the distribution of weed populations and soil invertebrates. The third paper in this session provided an example of an approach for developing indices for tillage intensity and herbicide use that might be used as indicators of management inputs in cropping systems.

The purpose of the final session of the workshop was to develop recommendations for the management and operation of the nine cropping systems during the next 6-year rotational cycle. In preparation for the final session, each researcher was asked to list possible changes to the cropping systems, identify gaps in data collection, and state their research plans for the next cycle during their presentations in the previous sessions. Ample time had been allowed for discussion after each presentation and for general discussion after every three or four presentations. We are very grateful to Terri Sittler and Brian Galka who recorded the salient issues raised in these discussions and collated these issues, with the changes, gaps and plans from the researchers, into a list of points for discussion. Their conscientious assistance resulted in a focussed and thorough discussion that led to the development of a number of recommendations for the next six years.

The workshop presentations from the project participants, the major points from the discussions, and the recommendations are captured in these proceedings. Special thanks are extended to Terri Sittler and Brenda Bauml who collected the contributions, formatted the chapters, and prepared the proceedings for printing. Finally, the organizing committee acknowledges the support, cooperation, enthusiasm and dedication of the scientists and technical support staff who are part of the project team. Without their special contributions, the workshop would not have achieved its goal.

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A. Gordon Thomas, Stewart A. Brandt, Daniel Ulrich and Owen Olfert
Workshop Organizing Committee

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Long-Term Agro-Ecosystem Research for the Canadian Prairie Ecozone

Research Farm
Scott, Saskatchewan

Executive Summary

A. Gordon Thomas[1] and Stewart A. Brandt[2]

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Introduction

- The overall goal of the Alternative Cropping Systems Project was to initiate and maintain a long-term multi disciplinary cropping system experiment at Scott, Saskatchewan to evaluate the sustainability of arable crop production on the Canadian Prairies.

- The experiment started in 1994 with the entire site cropped in barley. A quantitative characterization of the study site in this year provided baseline data on physical and biological components that can be used to assess the direction and rate of change in the cropping systems. The first 6-year cycle begin in 1995.

- The experimental framework is a matrix representing three levels of input use and three levels of cropping diversity that results in nine cropping systems. The three input levels are organic (ORG), reduced (RED) and conventional (HIGH) and three cropping diversity levels are low (LOW), diversified annual grains (DAG), diversified grain/forage (DAP).

- A 4-replicate split-plot experimental design with input level as the main treatment and cropping diversity as the split plot was successfully established in 1995. Each cropping diversity level consisted of a 6-year rotation cycle with all phases present each year. The integrity of each of the nine systems was maintained through to 2000 for completion of the first 6-year rotation cycle. Individual plots are 12.8 m by 40 m plots in size. The experimental site occupies 16 ha and has 216 plots.

- The first 6-year rotational cycle ended in 2000. Data on various components of the systems have been collected and analysed annually. Some components were measured in more detail at the end of the first cycle by collecting samples either in the fall of 2000 or in early spring of 2001.

- A workshop was held at the end of the first 6-year cycle to review what had been accomplished by project participants, to summary progress, and to plan for the next 6-year cycle.

Project Activities

Crop Production

Objectives

- Establish a permanent micro-met station to measure the following meteorology parameters: air and soil temperature, relative humidity, rainfall, and solar radiation. The station was configured to record meteorological data that would enhance interpretation of agronomic, arthropod, weed, soil, pathology and economic data.
- Evaluate crop yield as the primary indicator of the productivity of each of the systems. Use crop yield information to evaluate economic and energy performance of these systems. Compare the yield averaged over all phases of each system provides as an indication of the productivity of the system. Compare the same crop or cropping phase of different systems to provide some insight into the major factors contributing to yield differences.
- Determine the potential for wind erosion in the first cycle of low, reduced and high input systems in combination with low, diverse annual and diverse annual perennial crop rotations.
- Summarize the information from sampling soil every year in fall after harvest to determine the influence of input level and cropping diversity on accumulation and distribution of nitrate-N and extractable P in the soil under various alternative cropping systems.

Progress

- Each year a Campbell Scientific CR-10 data logger was installed and was operational from early April until October. Data have been summarized, presented in annual reports and uploaded to a database that participants can access to obtain daily, monthly, and growing season summaries (1995-2000 growing seasons).
- Averaged over the 5 year period 1996-2000, yield of the High and Reduced input systems were similar while the Organic systems were about 30-50% lower. With High inputs, yield showed a slight tendency to be higher than for Reduced inputs, but the difference was small.
- With High and Reduced inputs, the LOW diversity system was lowest yielding, and the DAG system highest yielding, with DAP intermediate (1996-2000 averages).
- With Organic inputs, the LOW and DAG systems were lowest, and DAP highest yielding (1996-2000 averages). Relatively poor performance of the DAG system with Organic inputs was related to the 2 green manure crops which were replaced by annual grains in the High and Reduced input systems.
- Protein yields generally followed similar trends as crop yield, although low protein content of forages in the DAP systems reduced their relative protein yield compared with LOW and DAG diversities. Generally the protein concentration of High input cereal grains was greater than for Reduced or Organic inputs, reflecting a greater supply of nitrogen.
- Annual precipitation and stored soil moisture explained much of the year to year variation in yield. With normal or above normal moisture in 1996, 1999 and 2000, yields were high, and lower during the drought years of 1997

and 1998.

- The amount of nitrogen supplied to the crop from both the soil and fertilizer along with weed competition explained much of the yield difference between input systems and between individual crop phases within systems. Because no fertilizer was applied in the organic systems, N supply was low, and yield of most crops was reduced, except where N fixing legumes were grown. Residual soil N with the Reduced input systems that were direct seeded, were typically lower than for the High input systems with conventional tillage. It appeared that elimination of tillage reduced mineralization of N from organic matter, and occasionally reduced yield.

- Weeds reduced yield of organic crops in most years. Organic canola was usually most affected, but organic cereals were impacted in several situations.

- Other factors affecting yield included reduced spring soil water following green manures compared with conventional summer fallow; delayed seeding with Organic canola compared with High and Reduced; poor establishment of perennial forages; and suspected herbicide residue damage following High input canola. Green manures did not consistently reduce spring soil water, typically occurring when precipitation was limited after green manure plow down. Delayed seeding was employed as a tactic for controlling annual weeds in the Organic systems, and while it may account for some yield reduction with other Organic crops, it's impact on Organic canola was usually very evident. Perennial forages failed to establish in years when spring precipitation was limited, and in most cases was replaced by a pea-oat mix. Soil incorporated herbicide applied for weed control in canola appeared to cause some damage to the following High input wheat crop during dry periods. This damage may have been related to non-uniform distribution of the herbicide cause by tillage done in one direction only on the relatively small plots.

- The potential for wind erosion was significantly higher in spring following fallow and lower following fall rye. Spring and fall tillage in organic systems reduced the amount of residue compared to reduced input systems

- In general, greater amounts of nitrate-N in 0-36" soil were found at HIGH input level, especially under LOW cropping diversity. The nitrate-N in various soil depths suggest some downward movement of nitrate-N in the soil profile when HIGH input was compared to ORG. In LOW cropping diversity, green manure or summerfallow usually had more nitrate-N in soil than the other treatments. In DAG and DAP cropping diversities, nitrate-N varied with crops (on average highest after wheat or canola in DAG and after hay followed closely by wheat in DAP. In some instances, ORG input level had greater nitrate-N than RED. This may be most likely due to lack of P in soil for optimum crop growth. HIGH or RED input levels tended to have more extractable P in the 0-6 and 6-12" soil depths than the ORG input level in many cases in all years. These was no consistent effect of cropping diversity on extractable P in soil.

Economics and Energy

Objectives

- Compare production costs, economic returns, and riskiness of the nine cropping systems.

- Compare non-renewable energy inputs, energy output, and energy use efficiency of nine cropping systems.

Progress

- Economic performance of the nine production systems varied among years, and depended greatly on the eligible quantities of product sold into the organic market (or the price premiums received for organically grown grains).

- Crop diversity treatment, DAG, is most profitable under wet conditions despite its higher costs of production, and LOW is best under dry conditions. The DAP system was not economically competitive under the price assumptions used in this analysis, in part due to the lack of a direct price premium for organically grown forage hay.

- High input management was more profitable in wet years when the response to management inputs (e.g., fertilizers and pesticides) is greatest due to the favourable growing conditions. The reduced input management treatments, with its lower cash outlay requirements, performed well in dry years, and may represent a good risk management strategy for drought situations.

- Organic input management was more profitable than the high input or reduced input management systems under the 1996/97 - 1998/99 price premium levels that existed for organic grains.

- Fertilizer (primarily N) and fuel were the major non-renewable energy inputs to all treatments, except organic treatments where fuel alone was the major energy input.

- Gross and net energy production tended to be highest for DAG, intermediate for LOW, and lowest for DAP treatments and gross energy production tended to be highest for high input and reduced input treatments and lowest for organic input treatments.

- Organic input levels showed potential to reduce total energy inputs by up to 50% compared to high input and reduced input treatments. Non-renewable energy use efficiency was highest with organic input management.

Soil Biota

Objectives

- Investigate the effect of input intensity and cropping diversity on biodiversity of arthropods on the soil and in the soil.

- Compare the ecological impact of cropping systems on the soil fauna relative to four uncultivated grass sites

- Assess the spatial distribution, species diversity and relative abundance of arbuscular mycorrhizal fungi (AMF) as a result of changes in input and cropping systems, determine the susceptibility and/or affinity of crops to AMF, and determine the relationship between AMF parameters and yield, weed and disease parameters.

Progress

- A baseline data set of arthropods in crop (sweep samples), on soil (pitfall trap samples) and in the soil (core extractions) has been compiled from 1994/95 sampling data.

- The beneficial arthropods living on the soil, in decreasing abundance, included Collembola, Arachnida, Coleoptera, Homoptera, Hymenoptera, Diptera and Hemiptera based on pitfall trapping. Ground beetle populations (Coleoptera: Carabidae) were influenced by the treatments; abundance and species richness highest in the organic input system and highest in the diversified annual grain rotation based on pitfall trapping

- The arthropods living in the soil, in decreasing abundance, included Collembola, Acari, Coleoptera, Hymenoptera and Diptera based on extractions from soil cores. Soil mites populations (Acari) were influenced by the treatments; abundance was highest in the reduced input system and the diversified annual grain rotation. The Sub-Orders of Acari responded differently to the treatments; Oribatida abundance was highest in the reduced input system and decreased with the level of soil disturbance; Astigmata abundance was highest in the organic input system and increased with the level of soil disturbance.

- The soil micro-fauna within the crop land, in decreasing abundance, included nematodes, rotifers, protozoans, enchytraeids and tartigrades. Micro-faunal populations were influenced by the treatments; nematode and rotifer abundance was highest in the reduced input system and the diversified annual grain rotation; protozoan and Enchytraeid abundance was the lowest in the high input system; no Tartigrades have been recorded to date in the low crop diversity rotation.

- Variability in the numbers and spatial distribution of the AMF propagules exit at the field site.

- Highest level of mycorrhizal root colonization occurred with crops grown under the organic input system, while root colonization was similar in the high and reduced input systems. Crops grown under the grain/forage rotation yielded significantly higher root colonization than crops grown under the low and annual grains rotation system.

Insect, Disease and Weed Pests

Objectives

- Investigate the effect of input intensity and cropping diversity on dynamics of crop pest species.

- Determine the effect of management practices (inputs and cropping diversity) on field crop diseases.

- Characterize the leaf spotting populations in wheat, barley and fall rye to determine treatment and environmental effects, and whether any differences in leaf spotting disease severity might be attributed to a differential effect on the leaf spotting pathogens.

- Quantify the composition of the residual weed community and examine the yearly change in density of important species using Principle Response Curves to provide a concise summary of the year to year variation of the weed community associated with the nine cropping systems.

- Determine the impact of three levels of inputs and three levels of cropping diversity on weed competition as measured by pre-harvest weed biomass, evaluate the effectiveness of weed control strategies within each system and determining how the climate interacts with management decisions to affect weed biomass.

- Identify the weed species removed by chaff collection and quantify the amount of seed removed.

Progress

- No post-emergent insect control was required prior to 1999; however, in 1999 and 2000 insecticidal sprays were applied to control wheat midge and grasshoppers in high input plots.

- The occurrence and severity of plant diseases between 1995 and 2000 were influenced more by general climatic variations from year to year than by crop input level or cropping diversity. The greatest impact of input level decisions occurred in wheat and barley when fungicides were applied in the high input system in 1999 reducing disease on flag and penultimate leaves in wheat and penultimate leaves of barley.

- Under moist climatic conditions Harrington barley in the diversified annual grains (DAG) system and wheat grown on wheat stubble within the LOW diversity system are especially vulnerable to disease infection and yield loss and therefore the most likely to respond to fungicide application with increased yield.

- Differences in leaf-spotting diseases in barley between cropping diversities and in canola between levels of inputs were primarily a function of variety selection and inherent disease resistance differences. However in the case of canola a later seeding date for Brassica rapa canola used in the organic input system than B. napus used in the high and reduced input systems likely also contributed to greater blackleg severity in the organic system.

- Despite higher levels of disease within wheat phases of the LOW diversity system resulting from frequent wheat production within the 6-year rotation, a comparison across diversity levels showed cropping diversity systems had no impact on levels of disease in wheat. Not surprising a 6-year crop rotation for field pea, barley, fall rye and canola in each of the 3 cropping diversities were effective in minimizing plant diseases.

- Leaf spotting pathogen populations were determined in the common wheat and barley cultivars in each of the treatments where they were grown from 1997 to 2000 and in the fall rye treatments in 1999 and 2000.

- Assessed residual weed communities in all 54 treatments in the site characterization year and each year from 1995 to 2000. Identified Principle Response Curves as an appropriate method for tracking changes in weed communities. Applied Principle Response Curves to illustrate that weed communities in the organic systems appeared to reach an equilibrium after a 3-year transition period, while the problematic weed species in the reduced input system were still increasing after six years. Green foxtail, lamb's-quarters and stinkweed were identified as problematic species in the organic input systems and wild oats, shepherd's-purse and narrow-leaved hawk's-beard were identified as problematic weeds in the reduced input system.

- In-crop herbicide applications in the Reduced and High input systems produced less in-crop weed biomass then pre- or post-seed tillage operations in the Organic system by delaying weed growth and reducing the risk associated with precipitation timing.

- The three different levels of cropping diversity showed similar weed biomass trends over time. Greater weed biomass in the diversified annual grains system could be attributed to weed control problems in the Organic input system and to a lesser extent in the High input system.

- In the organic input system large variations in grassy, broadleaf and volunteer weed biomass occurred within years and between years suggesting additional years of data are required to identify trend differences between diversities.
- Seeds from the current crop were the major species found in the chaff. Canola seed density ranged from 1300 to

2900 per m^2 and wheat seeds ranged from 200 to 300 per m^2. Small seeded weed species (lamb's-quarters, shepherd's-purse, and stinkweed) were the most abundant species found in the chaff. Only a small percentage of the total lamb's-quarters and stinkweed seed production is removed in chaff; however, direct harvesting is more efficient at removing stinkweed seed than swathing.

- Lack of a weed biomass reduction on plots where chaff was collected suggests that any reduction in the weed seedbank has to date been too small to reduce weed competition.

Soil Quality

Objectives

- Conduct site characterization work prior to establishing treatments to establish a baseline from which change over time could be measured and to account for biases in the data set caused by spatial variability.
- Investigate the effect of input intensity and cropping diversity on selected physical, chemical and biological soil quality indicators. Determine most effective "suite" of soil quality indicators
- Characterize soil properties that affect soil erosion in the site characterization year.

Progress

- Soil samples from two depths (0 to 7.5 and 7.5 to 15 cm) were collected from all plots at the end of the 2000 growing season for physical, chemical and biochemical analysis and subsamples were archived. Detailed analyses will be performed on 36 selected wheat phases of all input by diversity combinations. Selected samples will be analysed for bulk density, pH, total organic C and N, light fraction C and N, water-soluble organic C, NO_3 leaching, microbial biomass C and N, microbial respiration, soil enzyme activity, and specific respiratory activity.
- Established that after one cycle of the rotations, soil microbial activity was affected by cropping diversity and production system. The activity levels in the top 7.5 cm of soil were significantly higher than those found in the 7.5 – 15 cm soil depth. In the top depth, microbial activity consistently increased with decreasing level of inputs. Input level affected microbial activity near the surface much more than did crop diversity. The trends found in the 0 – 7.5 cm soil depth were not reflected in the lower depth.
- The spatial variability of sand, silt and clay particles, soil conductivity and bulk density were determined at the beginning of the study. The sand fraction varied considerably across the area with several high values near 80% in the northwest corner of the experimental site. The erodible aggregate fraction <0.84 mm was also high at the same locations as the sand fractions.

Interdisciplinary

Objectives

- Determine the contribution of topographic, soil physical, soil chemical and previous land use to observed patterns in weed populations and soil fauna prior to the establishment of experimental treatments.
- Investigate methods for calculating simple, weighted and modeled herbicide and tillage indices. Apply these

indices to the nine cropping systems and illustrate their use as indicators for describing systems.

- Design a database with the following features: facilitates communication of data/results between researchers, provides rapid access to specific data types, provides secure data archiving, accommodates database expansion, improves and maintains data integrity, and provides multilevel security.

Progress

- Established that spatial factors account for a large amount of the variance in weed populations and soil fauna from the site characterization year and that these factors should to be considered in the analysis of biological data.

- Ranked the nine cropping systems based on tillage and herbicide indices. Modelled indices gave the best separation of the nine systems.

- Developed and implemented Windows NT Groupshare (AAFC-Saskatoon Research Centre) for storage and shared data among project participants. Developed and administered a relational database (ACCESS) for arthropod, agronomy and ag-meteorology data.

Recommendations

- A number of changes to cropping operations are required to deal with problems that have arisen, and to ensure that the study continues to generate valid and relevant information.

- The on-site weather station requires modification or replacement to allow for additional data collection and summarization of data.

- A number of protocols for additional data collection need to be developed and costed, and applied to the study as resources come available.

- Some additional training of technical staff is required to enable new data collection protocols to be enacted.

- Expertise in multivariate statistics is essential to allow data to be evaluated in an interdisciplinary rather than multidisciplinary manner. This expertise is critical to developing an understanding of the interrelationships of components of cropping systems.

- Improvements to data storage and retrieval are essential to accommodate and utilize the large volumes of data collected and anticipated over the course of the study. In addition, efforts need to be intensified to ensure that all data collected to date is entered into the central database.

- Detailed plans for the in-depth evaluation of the study at the end of the second cycle (2006) need to be developed by 2004. This will allow plans to be developed to ensure that resources can be put in place to meet the need.

- Consideration needs to be given to developing and obtaining support for complimentary studies designed to develop technologies to address some of the shortfalls of systems identified to date by this study.

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Research Farm
Scott, Saskatchewan

Introduction

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Project Rationale

The overall objective of Scott Alternative Cropping System project is to evaluate the sustainability of conventional and alternative crop production systems in the Prairie Ecozone. Alternative production systems are needed to meet demands for food while preserving or even enhancing the ability of future generations to meet their needs. Possibilities include reducing non-renewable inputs by substituting alternative production practices such as diversified crop rotations, integrated pest management, nitrogen-fixing legumes, and reduced tillage systems. While some of these practices have been evaluated for their short-term impact on crop production and economics, none have been evaluated for their long-term impact on sustainability. Controlled-factor experiments, though powerful and useful, are inadequate to address larger questions related to ecological interactions of whole systems and their long-term environmental and economic sustainability. The design of the project is unique in that, unlike controlled factor research, this project can adapt over time to accommodate the newly developed technologies that reflect innovative farming practices. The project objectives reflect a vision of maintaining a long-term study as an evolving learning centre where issues of sustainability can be addressed and shared regionally and with others worldwide. Long-term cropping system studies serve two essential functions. Firstly, they provide advance warning of weaknesses in production systems allowing the industry time to develop new strategies before a crisis arises. Secondly, they generate understanding of the principles that drive agroecosystems. This understanding is essential in developing strategies to address sustainability weaknesses or take advantage of system strengths.

Workshop Rationale

The project is designed to evaluate the sustainability of nine arable crop production systems using a 16 ha experimental study site for a minimum of 18 years at Scott, Saskatchewan. The nine systems are derived from combinations of three input levels (organic, reduced and conventional) and three cropping diversity levels (low, diversified annual grains, diversified grain / forage). The first 6-year rotational cycle ended in 2000. Data on various components of the systems have been collected and analysed annually and will continue during the second cycle. Some components were measured in more detail at the end of the first cycle by collecting samples either in the fall of 2000 or in early spring of 2001. It is an appropriate time to review what has been done, to summary progress and plan for the next cycle.

During the past seven years, project participants have focussed on describing and analyzing the impact of the experimental treatments on system components that are relevant in their individual disciplines. In this sense, the project is considered multidisciplinary. Although much valuable information has been collected, it is recognized by the workshop organizing committee that the focus of the project needs to expand from a disciplinary based to a systems level inquiry. The discipline information needs to be considered as input into an interdisciplinary inquiry. One obvious way of encouraging this approach is to hold a project workshop to share information collected during the first cycle. The goal of an interdisciplinary agroecosystem study is to analyze and improve the systems. To do this, an understanding of the "essence" of the systems and its strengths and weaknesses is needed. This will only happen if an interdisciplinary approach is adopted. Collectively the project participants can solve practical problems that prevent systems from achieving a target level of sustainability.

Workshop Objectives

1. Review progress and accomplishments of the research team during the first 6-year cycle.
2. Establish guidelines for changes to and management of the nine systems during the next 6-year cycle.
3. Develop detailed plans for the next 6-year cycle.
4. Identify gaps in the current research plan and discuss options for addressing them during the next cycle.
5. Foster linkages with other scientists and agencies.
6. Initiate discussions on the development of physical, chemical and biological indicators that are appropriate for assessing the sustainability of cropping systems.

Alternative Cropping Systems

ACS Long-Term Agro-Ecosystem Research for the Canadian Prairie Ecozone
1994 - 2012
Research Farm
Scott, Saskatchewan

Review of Study Design

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Rationale

Wheat-fallow rotations prior to 1980 were the primary crop production systems on the Canadian prairies providing a means of normalizing returns by minimizing the impact of year to year variations in precipitation patterns and supplying an ever present demand for quality wheat. Since 1980 however a number of issues have generated significant change. Long term rotation studies as reported by researchers such as Cambell et al. (1993) and Biederbeck et al. (1994) were instrumental in associating soil organic matter loss with mechanical tillage. With the adoption of minimum and zero tillage practises came research showing that cereal rotations could be extended and yields enhanced when pulse crops were incorporated into the rotations (Stevenson et al. 1996). Although agronomic research provided the initial impetus to change crop production practices, economic realities have accelerated the adoption of different crop production systems as producers respond to low commodity prices, rising costs of production, and changing consumer demands. Environmental concerns regarding fertilizer and pesticide use and movement of residues to non target areas, cadmium uptake, green house gases, and soil carbon sequestration have in recent years been added to the long list of concerns shaping the way we view crop production. To address some of these concerns while at the same time maintaining producer profitability much research effort has gone into investigating various components that when combined define a production system. While such research is valuable in identifying useful components of a production system it falls short of providing insights into component interactions and their long term implications within a production system. Current long term rotation and tillage studies provide a wealth of information on soil degradation, soil quality, nutrient dynamics, crop production and quality and to a lesser extent economics. However, they are unable to contribute to our understanding of the long term impact of a production system as defined by its individual components and their interactions on economic, soil quality and environmental issues. Issues surrounding the impact of agriculture on water quality, biological diversity, food safety, impact of manuring and altered levels of inputs requires long term studies that are best addressed through a systems approach. By comparing input use and cropping diversity on a system level a broad range of crop production practises can be investigated. With sustainability as the one goal which encompasses all elements of a production system the primary focus of a new long term study was to provide guidelines for the development of sustainable arable crop production systems on the Canadian Prairies based on the five pillars of Sustainable Land Management using three levels of production inputs and three levels of cropping diversity. The five pillars of sustainable land management as defined by A.J. Smyth and J. Dumanski, 1993;

" Sustainable land management combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously:
-maintain or enhance production/services (Productivity)
-reduce the level of production risk (Security)
-protect the potential of natural resources and prevent degradation of soil and water quality (Protection)
-be economically viable (Viability)
-and socially acceptable (Acceptability)."

Methods

Site Characterization

Due to the nature of soil and climatic variability on the Canadian prairies the study was established in 1994 at Scott, Saskatchewan (520 22',1080 50', elevation=713 metres) near the geographic centre of the Canadian Prairies in the Dark Brown soil zone between the semi-arid and sub-humid prairies. A topographical survey of the area revealed a general 0.6 degree slope across the 18.5 ha site decreasing in elevation from east to west by approximately 3.5 meters with good surface drainage. Site characterization work was conducted in 1994 to identifying soil and biological properties and their variability to create a baseline from which change over time could be measured and to account for inherent biases in data sets caused by spatial variability. Work by Allan Moulin (Brandt et al.,1994) indicated bulk density to 15 cm and particle size distribution were relatively uniform at the site while aggregate size distribution, hydraulic conductivity, geometric mean diamter and erodible fraction were highly variable. Electrical conductiuvity, bulk density, silt and clay fractions, erodible aggregate fraction (<0.84 mm), and soil moisture were correlated with sand content which was observed to be high in the north west corner of the experiment.

Geometric mean diameter of the aggregates was correlated with silt content. Soil characterization work by Fernando Selles (Brandt et al.,1994) revealed soil bulk density was normally distributed to the 15 cm depth reflecting the impact of transient freeze-thaw and wetting-drying cycles, and soil managment practices. Spatial structure of soil bulk density below 15 cm to the 120 cm reflected the combined effects of geological and pedological processes. In the effort to determine N -supplying power of the soil, greater total N in areas of near level relief were observed suggesting organic matter may have been modified by erosion-deposition processes and exacerbated by cultivation. Biological baselines were identified by uniformly cropping the site and conducting weed plant and seed bank, mycorrhizal and anthropod surveys in 1994. Uniform barley cropping revealed low grain yield cv's of 9.2% with no significant differences observed between planned treatments affirming that the most appropriate experimental design had been used. Although site characterization work revealed considerably more variability across the site then expected it underlined the importance of baseline identification for understanding agronomic results, measuring change over time, and relating chemical and physical properties of the site to biological distributions.

Experimental Design

The experiment is a 4 replicate split plot experiment with main plot treatments consisting of 3 levels of inputs and sub-plots comprised of three levels of cropping diversity each on a six year rotation cycle. Input levels are described as Organic (ORG), Reduced (RED), and High (HIGH) and cropping diversity levels as Low, Diverse Annual Grains (DAG), and Diverse Annual Perennial (DAP). Main plots were 1.8 ha in size with 0.3 ha sub plots (see figure 1). Up to one third of each sub plot has been used for destructive sampling and to accommodate sub-sub treatments for more detailed study. The remaining area was used to maintain integrity of the main and sub treatments and to allow for future sub division. Input and cropping diversity levels have the following general definitions (Brandt et al., 1996).

Input Level

1. Organic (ORG): Pest control and nutrient management practices based on "non-chemical" means. Long term cultural pest control with organic green manures legumes used extensively with this treatment along with other

acceptable organically certified products. This treatment is an attempt to mimic what an organic grower would do within the constraints of the three diversification options.

2. Reduced (RED): This system uses integrated long-term management of pests and nutrients, with chemicals used to supplement other management practices. The objective is to reduce inputs (pesticides, fertilizers and fossil fuels) such that any yield reduction is more than offset by reduced input costs. Any appropriate technology that can be substituted for or used to reduce such inputs can be used. Typically new technologies would be incorporated into this treatment at an early stage and later into the Organic or High input system as appropriate.

3. High (HIGH): Pesticides and fertilizers used "as required" based on conventional recommendations associated with pest thresholds and soil tests. Long term management of pests and nutrients is of minimal concern as chemicals are used to respond to problems or deficiencies as they arise. (This treatment does not preclude use of cultural practices considered to be normal agronomic practice such as certified seed or pre-seeding tillage for weed control). Only those technologies typically in use can be employed with this treatment.

Cropping Diversity

1. Low (LOW): A wheat based rotation of fallow-wheat-wheat-fallow-canola-wheat reflect cropping systems chosen by risk averse producers. (With legume green manures used as fallow substitutes in the Organic system and where appropriate in the Reduced input system, but not the High input system).

2. Diversified Annual Grains (DAG): A rotation of a diversity of cereal, oilseed and pulse crops with the possibility of some crops used as annual forages for off-farm export or as green manures. The rotation could vary between input levels depending upon their requirements, but must include a spring cereal, an oilseed, a pulse and where feasible, a winter cereal. Actual choices from year to year for each input level would be based on conditions and requirements for each system. Fallow would only be an option if no other alternative existed. As a general guideline, a canola - winter cereal - pea - barley - flax - wheat rotation would be used. Recommendations by organic growers facilitated the incorporation of two green manure fallow phases into the ORG-DAG system to produce the following rotation GM fallow-wheat-pea-barley-GM fallow-canola. Where appropriate crops could be harvested as forage, but planned primary usage would be as grain. The winter cereal would be fall rye or winter wheat as appropriate.

3. Diversified Annual and Perennial (DAP): A mixed rotation of grain and forage crops following a oilseed-cereal-cereal-forage-forage-forage sequence with partial fallow after the first cut on third year forage stands. The same basic rotation used at all input levels but actual crop choices based on requirements for each. One cereal could be a feed grain and the first forage crop could be oats under-seeded to perennial forage cut for hay. This treatment would assume that a livestock operation was associated with the farm unit. The forage used should be alfalfa in the Organic system to meet some of the crop N requirements.

The livestock operation would be based on grazing from a land base unsuited to cultivation. Forages plus straw from the cereal rotation phases would be used as winter livestock feed along with grain from one of the cereals. Straw removed from the cereal phases would be offset by manure applications, based on amounts that could be generated from the forage and cereal inputs.

Results and Discussion

General cropping diversity models were altered along with management practices to accommodate the constraints imposed by each level of input and to improve the sustainability of each system. Within the Low diversity rotation fallow phases were managed differently for each of the three levels of inputs. In the Organic system fallow was green manured with the nitrogen fixing legume Indian Head lentils. In the Reduced system the first fallow phase was green manured using Indian Head lentils with leave strips left after incorporation followed by chemical fallow in the 4th phase. In the absence of a tandem disc all green manure material was mowed with a rotary mower and incorporated with sweeps. In the High input system fallow phases were mechanically tilled. In 1996, fall rye and flax were removed from the DAG diversity under the Organic input system to incorporate two nitrogen fixing green manure fallow phases (Indian Head lentils and Sweet Clover) providing a source of nitrogen and to enhanced weed control. The DAP diversity remained the same across all three levels of inputs. Additional treatment variances occurred between 1995 and 2000 generally due to poor crop establishment. Management of green manure crops was also altered periodically. A complete list of these variances can be found in table 1.

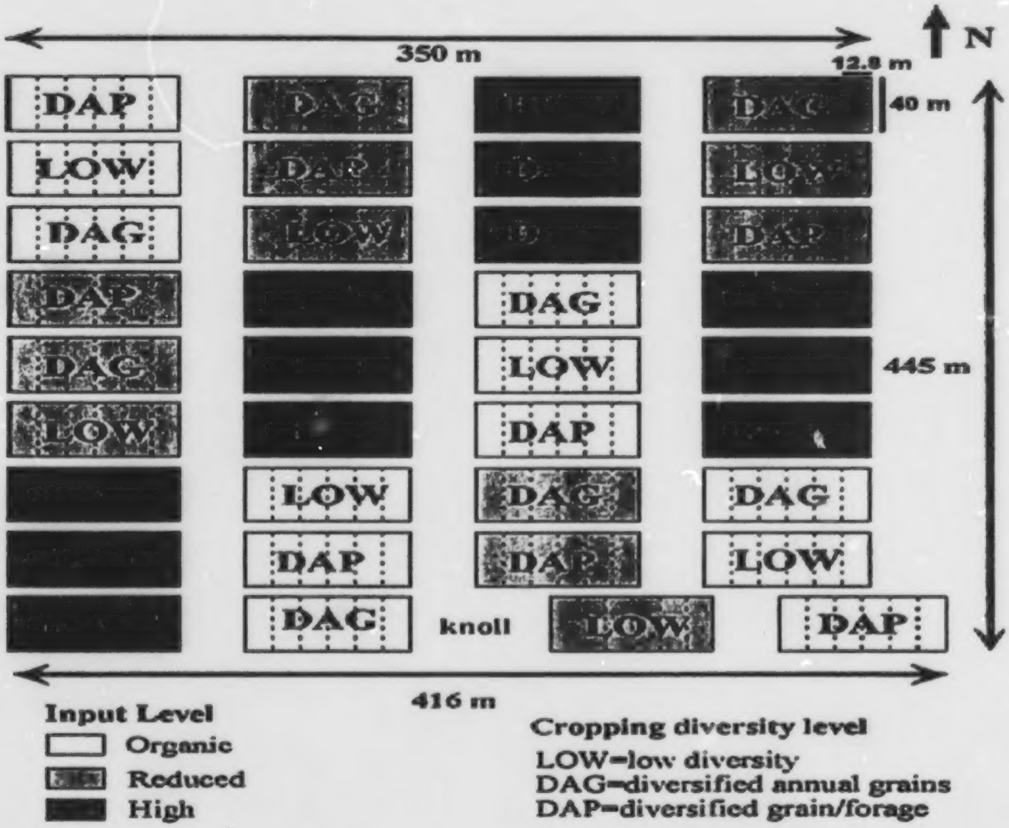
Crop varieties were altered slightly as older varieties were replaced by higher yielding varieties. Makwa was replaced by AC Barrie in 1999. The canola variety Reward (B. rapa) was grown in the Organic input system and B. napus in the Reduced and High input system (Cyclone from 1995-1997 and Hudson from 1998-2000). Field pea variety was updated from Radley grown between 1995 and 1998 to Espace in 1999 and 2000. Feed barley grown in the DAP diversity was Brier for all years except 1999 when AC Harper was grown. Other crop varieties included Harrington, Norlin flax, and Prima fall rye grown in the DAG diversity and Signal brome and Nordica alfalfa grown in the DAP diversity. Oats which was occasionally seeded as a forage crop in an oat-pea mixture was Boyer. Nitrogen fixing green manure fallow crops included Indian Head lentils and Sweet Clover.

The most significant management difference between input levels was the ban on chemicals and processed fertilizers and the sole reliance on tillage within the Organic input system. Seeding of annual crops in the Organic input system was generally delayed until the last week in May to enhance weed control and ensure quick germination and emergence of the seeded crop. In the Reduced and High input systems annual crops were typically seeded near the middle of May. In the Reduced input system products were applied on a plot by plot basis to more closely match application amounts with need in an attempt to reduce inputs. In the High input system product applications were based on requirements averaged over 4 replicates. A typical set of field operations and inputs for canola grown under High, Reduced, and Organic input levels is shown in table 2. An accurate and thorough recording of management activities within a systems based experimental design provides the opportunity to make comparisons between cropping systems on an operations level as well as a product input level. Figures 2 illustrates the distribution of annual tillage and herbicide operations between 1995 and 2000 for each system revealing a complete reliance on tillage in the Organic input system and greater emphasis on chemicals in the Reduced input system then in the High. Figure 3 illustrates in-crop weed control operation differences, between systems. An additional weed control measure included the collection of chaff from annual crops within the Reduced input system and from the barley, canola, and wheat plots in the DAG diversity of the Organic input system.. Table 3 summarizes annual nitrogen inputs between 1995 and 2000 with less nitrogen fertilizer required in the Reduced input system then in the High for the DAG and DAP cropping diversities but not for the LOW diversity. Less required N for the LOW-High system can be attributed to greater N mineralization occurring in the 2 mechanically tilled fallow phases then in the green manure and chemical fallow phases of the Reduced input system.

Data collection and analyses has been a collaborative effort by scientists from a broad range of disciplines. Similar to other long term soil and crop management studies data collection includes information on soil quality, crop productivity and economics. An extended data set however is also being generated on weed, insect and disease dynamics, including predator-prey dynamics in addition to pest-crop dynamics; movement of nutrients and pesticides from the production system; nutrient dynamics; quality of food produced both from a marketing and a nutritional viewpoint; net balance of green house gases; and development of mathematical models to quantify rates of change over time.

Evaluation involves a wide range of physical, biological, economic and social factors that exert a significant influence on the sustainability of each production system. To identify environmental change indicators of attributes associated with environmental change are in the process of being identified, and critical levels or thresholds of indicators are in the process of being determined as a means of evaluating sustainability. It is hoped this work in combination with indices developed by other researchers around the world will culminate in the development of sustainable indices for the Canadian Prairies.

Figure 1. Alternative crops study site plan.



N
350 m
12.8 m
40 m
445 m
416 m
knoll
DAP
LOW
DAG
Input Level
Organic
Reduced
High
Cropping diversity level
LOW=low diversity
DAG=diversified annual grains
DAP=diversified grain/forage

Figure 2. Average annual operations (tillage + herbicide) between 1995 and 2000.

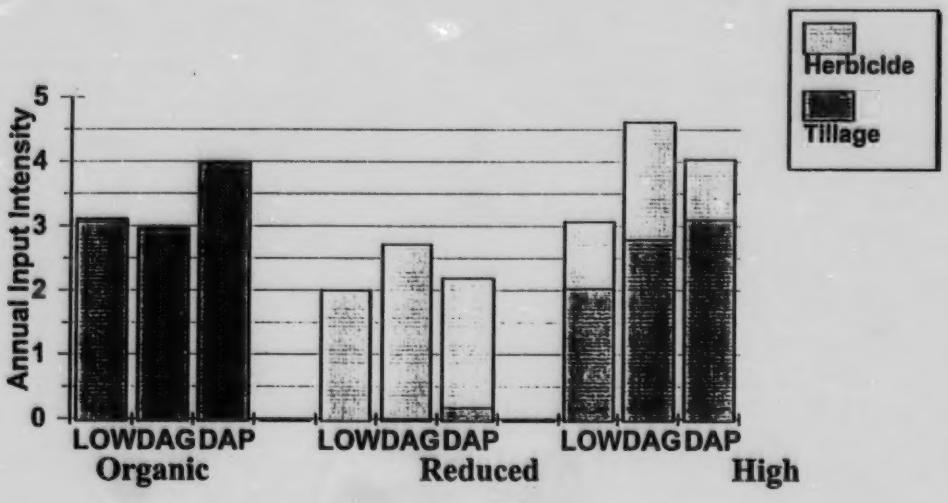


Figure 3. Average annual in-crop tillage and herbicide operations primarily for weed control between 1995 and 2000

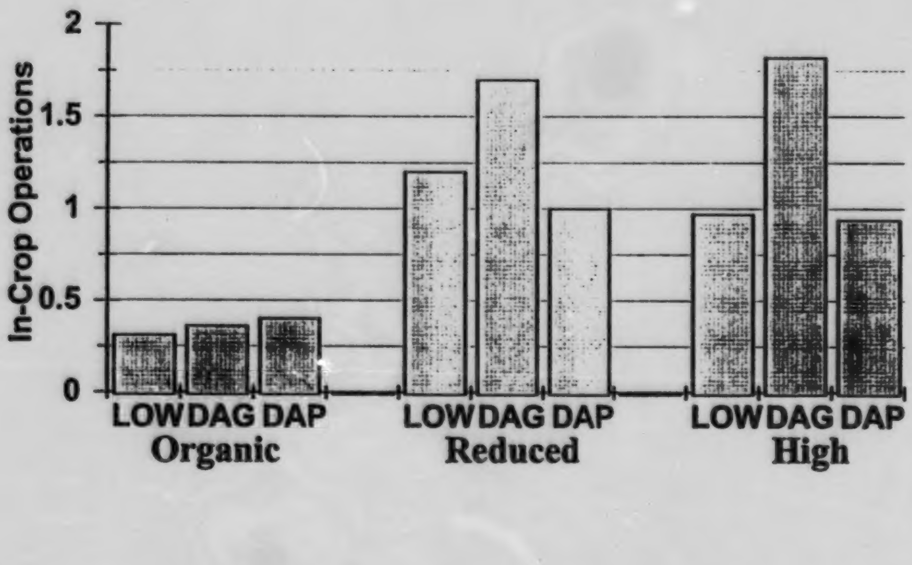


Table 1. Crop phases for 3 levels of inputs and 3 levels of cropping diversity along with treatment variances between 1995 and 2000.

			INPUT Level				
Diversity	phase	trt	ORGANIC	trt	REDUCED	trt	HIGH
LOW	1	1	Green Manure Lentil (j)	19	Green Manure Lentil** (j)	37	Tillage
	2	2	Wheat	20	Wheat	38	Wheat
	3	3	Wheat	21	Wheat	39	Wheat
	4	4	Green Manure Lentil (j)	22	Chemical Fallow	40	Tillage
	5	5	Rapa Canola	23	Napus Canola	41	Napus Canola
	6	6	Wheat	24	Wheat	42	Wheat
DAG	1	7	Green Manure Lentil (a,,j)	25	Napus Canola	43	Napus Canola
	2	8	Wheat (b)	26	Fall Rye (b)	44	Fall Rye (b)
	3	9	Field Pea	27	Field Pea	45	Field Pea
	4	10	Malt Barley (Sweet Clover)*	28	Malt Barley	46	Malt Barley
	5	11	GM Sweet Clover (c,,j)	29	Flax	47	Flax
	6	12	Rapa Canola (d,k)	30	Wheat	48	Wheat
DAP	1	13	Rapa Canola	31	Napus Canola	49	Napus Canola
	2	14	Wheat	32	Wheat	50	Wheat
	3	15	Feed Barley	33	Feed Barley	51	Feed Barley
	4	16	Oat(brome/alfalfa)*	34	Oat(brome/alfalfa)*	52	Oat(brome/alfalfa)*
	5	17	Brome/Alfalfa (e,g,i,l)	35	Brome/Alfalfa (e,g,l)	53	Brome/Alfalfa(e, g,l)
	6	18	Brm/Alf (f,g,h,l)	36	Brm/Alf (f,g,h,l)	54	Brm/Alf (f,g,h,l)

*crop was underseeded to crop in brackets

Treatment variances
(a) rapa. canola in 1995
(b) Brier barley in 1995
(c) flax in 1995
(d) wheat in 1995
(e) oat(brome/alfalfa) in 1995
(f) pea in 1995
(g) re-seeded to brome/alfalfa in August of 1995
(h)oat/pea in 1997 due to poor brome/alflafa establishment
(i)reseeded to brm/alf in October of 1998 due to poor establishment
(j)lentil&sweet clover having set seed were removed as forage 1999
(k) worked under in 2000-no yield
(l) seeded to oat/pea in 2000 due to poor brm/alf establishment

**Treatment 19: green manure lentil sprayed with non-selective herbicide, area between 0.5 m wide leave strips was mowed and cultivated with sweeps to incorporate, chemicals used to control weeds after incorporation.

variances: 1996- after incorporation cultivated between strips Aug 19
1997- desiccated on July 24. Mowed except for strips, no incorporation.
1999- lentils were cut and removed as forage.
2000- mowed July 20, no incorporation, strips left. Desiccated Aug. 17th

Table 2. Illustration of management differences among three levels of inputs for canola grown within the

diversified annual grains rotation of the alternative cropping study.

Operation		Organic	Reduced	High
Fall applied herbicide			granular +2,4-D	granular + HDC
Pre-seed weed control/ seedbed		2 x HDCwth		HDCwth
Seed	implement	double disc	hoe drill	hoe drill
	date	late May	early May	early May
	canola variety	*B. rapa*	*B. napus*	*B. napus*
	seed treatment	enhance phos. uptake	disease+flea beetle	disease+flea beetle
	applied N & P		$N_{(mrb)}$ $P_{(below\ seed)}$	$N_{(deep\ band)}$ $P_{(below\ seed)}$
In-crop weed control		harrow	herbicide	herbicide
Harvest		direct combine	swath + combine	swath + combine
Post harvest weed control		2 x HDCwth	fall 2,4-D ester	HDC

HDC-heavy duty cultivator, wth- with harrows, mrb-mid row band

Table 3. Mean annual level of applied N (kg/ha) for different input and cropping diversity levels during the first six year crop rotation cycle (1995-2000).

Crop Diversity	Organic	Reduced	High
Low	0.0	25.5	25.5
Diverse Annual Grains	0.0	33.1	37.9
Diverse Annual Perennial	0.0	25.1	30.5

Acknowledgements

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The technical expertise of Larry Sproule and Don Gerein from Scott in establishing and maintaining the experiment is greatly appreciated.

Alternative Cropping Systems

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Prairie Ecozone
Research Farm
Scott, Saskatchewan

Agricultural Meteorology Report for the Alternative Cropping Systems Project

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Rationale

Weather has a significant impact on agricultural systems. Collection and analysis of meteorological data can enhance interpretation of agronomic, invertebrate, weed, soil, pathology and economic data. Environment Canada weather stations collect meteorological data at the synoptic scale. Synoptic meteorological data is useful for understanding meteorological systems at the regional scale. Mesoscale meteorological data provides data that is useful for analysis of meteorological systems at the local scale. Microscale configurations are designed to record user-specific parameters. The Alternative Cropping Systems (ACS) weather station is a micro-met station that has been configured to collect data that addresses the specific needs of this project while still fulfilling the requirements of a mesoscale configuration.

Methods

A Campbell Scientific CR-10 datalogger was used for data collection of meteorological measurements including air temperature (1.5 m height), soil temperature (5 and 10 cm depth), relative humidity (1.5 m height), rainfall, and solar radiation (1.5 m height). The weather station was commissioned in early April and decommissioned in October. Meteorological events were recorded every 20 minutes. The datalogger was programmed to provide 24 hour summaries including mean, maximum, minimum and total values for each sensor.

On May 2, 2000 the weather station was analysed to confirm that all probes were operating properly. Temperature (soil) probes had not been verified for depth or calibration since the original installation in 1995. The soil probes were at 12.0 (probe 1) and 18.5 (probe 2) cm depth, not the expected 5 and 10 cm depth. The probes were placed in ice water to verify calibration. Probe 1 was recording temperatures between 1.15 and 1.69 0C. This probe was replaced with a new probe. Probe 2 was operating within expected limits. Probe 1 was placed at 5 cm and probe 2 was placed at 10 cm. The probes had been placed beneath turf grass (seeded in 1996). On May 2, 2000 probes were placed in cultivated soil immediately east of the weather station. On May 24 this area was seeded with wheat (the soil probes were removed and replaced). Each year soil temperature probes will be removed and calibration/depth will be verified. Wheat will be seeded over the area where probes are placed. The soil temperature data for the period of 1995-2000 should be treated with caution.

Data was summarized to provide mean air temperatures and total precipitation by month or growing season (May 1 to August 31). For relative comparisons, these values were compared to 1) mean monthly or growing season values for the 1995-2000 period and 2) mean monthly or growing season values based on Long Term Normals (LTN). The LTN are based on Environment Canada data for Scott SK. 1961-90.

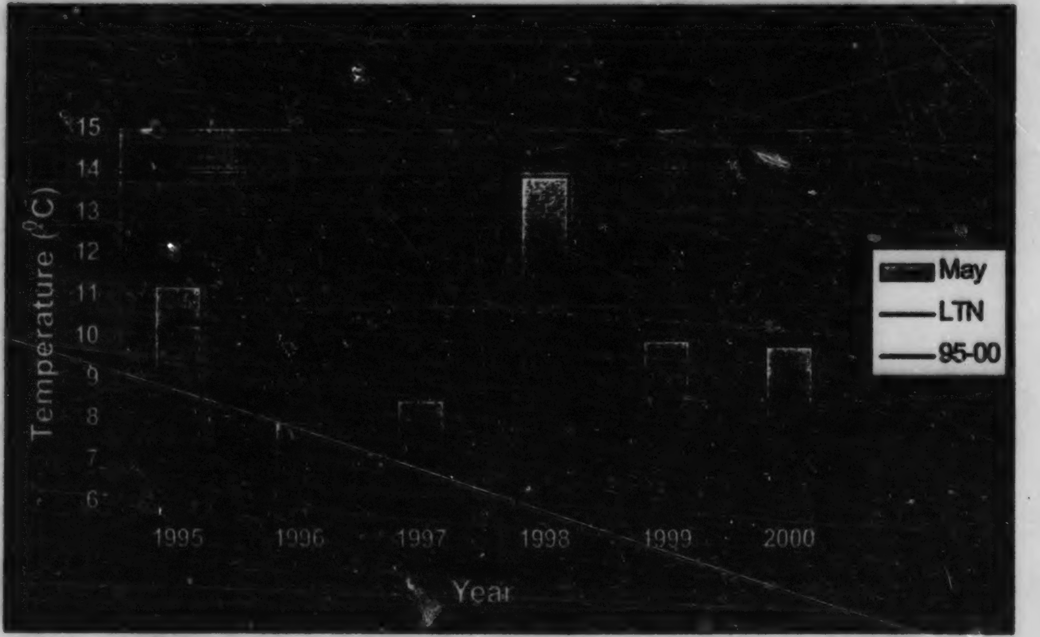
Results and Discussion

Monthly Temperature Analysis

May

The May monthly mean temperatures for the period of 1995-2000 were very similar to LTN. The 1995-2000 mean temperature was 0.1 0C greater than LTN (10.3 0C). Mean monthly temperatures were greater than LTN and 1995-2000 mean temperature in 1995 and 1998 (Figure 1). The warmest May (1998) was 3.5 0C warmer than LTN and 1996 was 2.5 0C cooler than LTN.

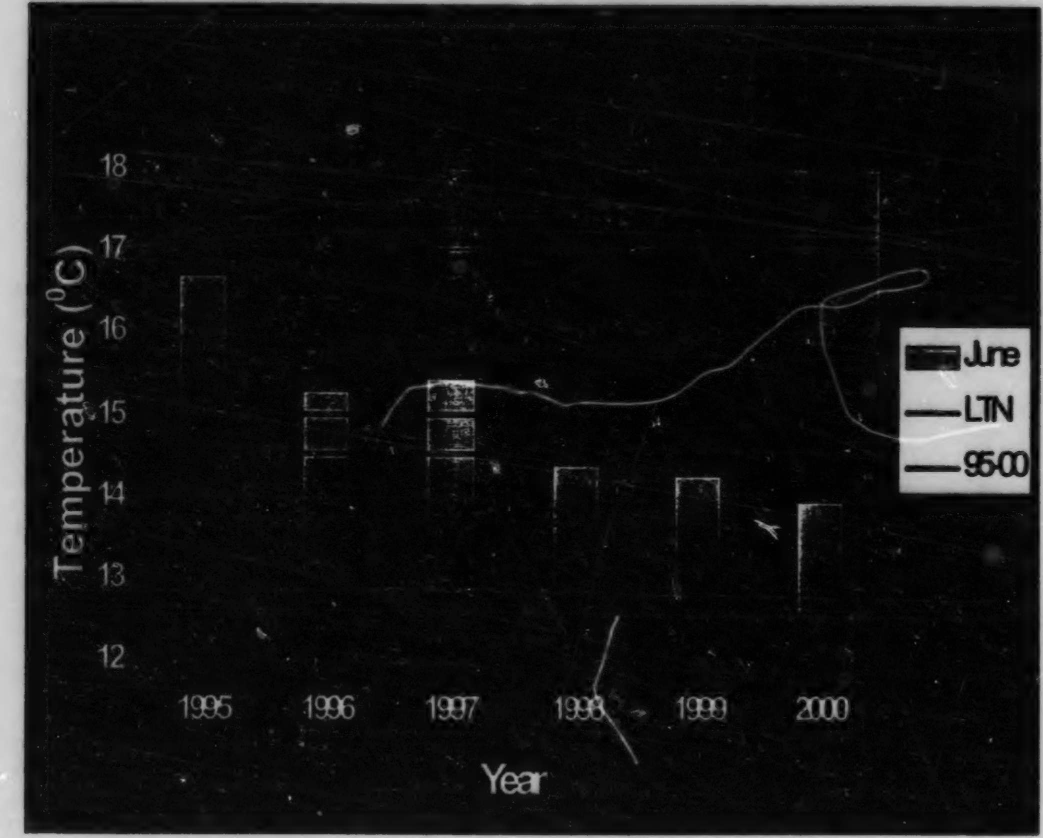
Figure 1. Air temperature (°C at 1.5 m height) measurements for May (mean monthly, growing season (1995-2000) and LTN) at Scott, SK. Monthly values for temperature represent monthly means. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



June

June temperatures for the first rotation were 0.5 0C warmer than the LTN (14.5 0C). There was a gradual decline in recorded temperatures between 1995 and 2000 (Figure 2). The variation between the warmest June and the coolest June (2.9 0C) was less than May (6 0C). The warmest June (1995) was 1.7 0C warmer than LTN and 2000 was 1.1 0C cooler than LTN.

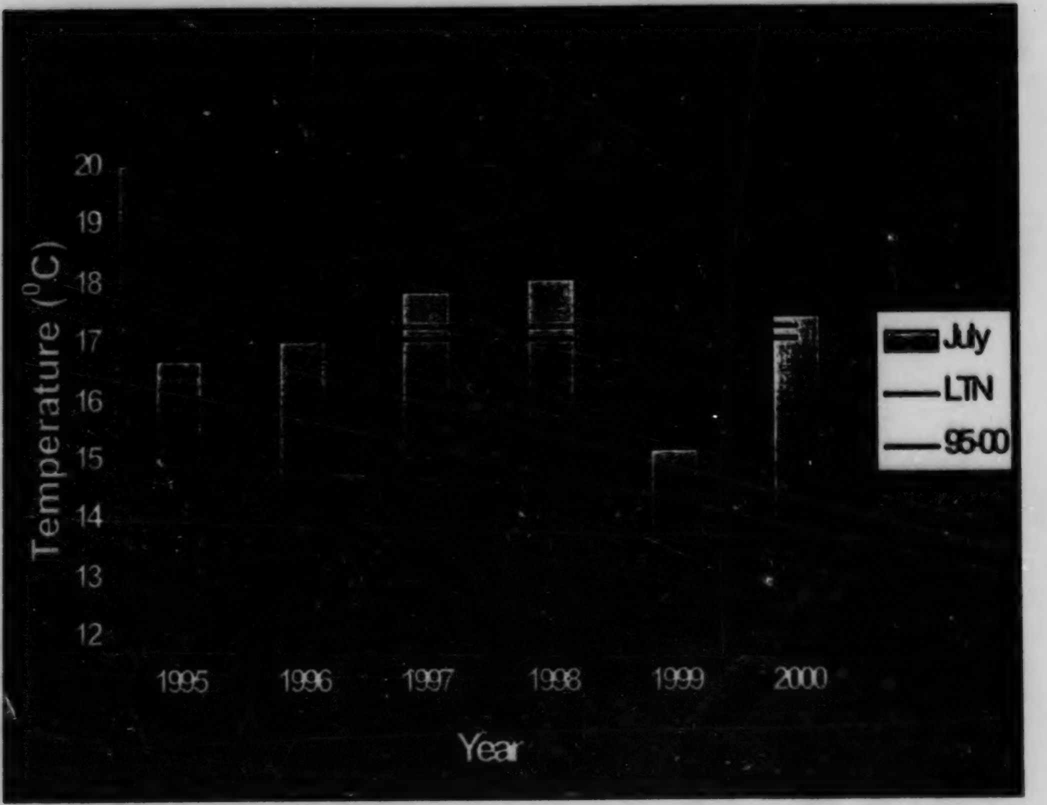
Figure 2. Air temperature (0C at 1.5 m height) measurements for June (mean monthly, growing season (1995-2000) and LTN) at Scott, SK. Monthly values for temperature represent monthly means. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



July

July temperatures for the first rotation were 0.2 0C cooler than the LTN (17.2 0C) (Figure 3). The variation between the warmest and coolest July (2.9 0C) was the same as June. The warmest July (1998) was 1.0 0C warmer than LTN and the coolest July (1999) was 1.9 0C cooler than LTN.

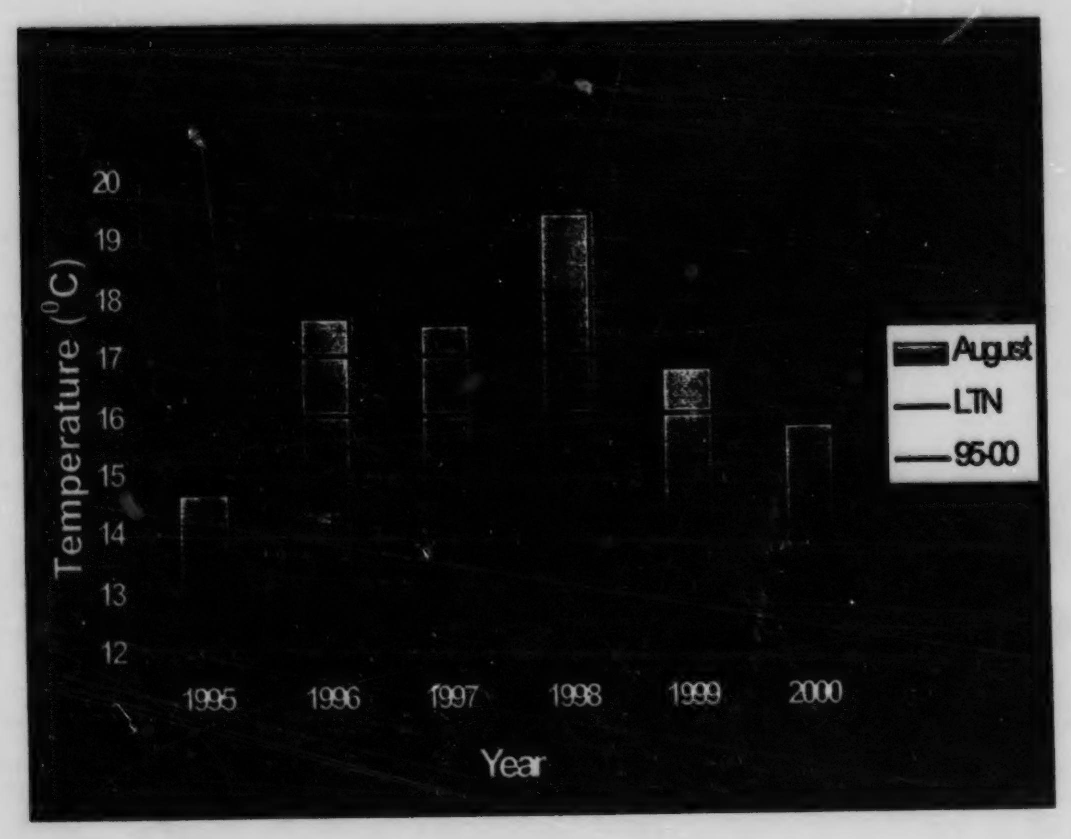
Figure 3. Air temperature (0C at 1.5 m height) measurements for July (mean monthly, growing season (1995-2000) and LTN) at Scott, SK. Monthly values for temperature represent monthly means. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



August

The August 1995-2000 mean temperature was 1.0 0C warmer than LTN (16.0 0C) (Figure 4). This was the largest monthly deviation from LTN. The variation between warmest and coolest August was 4.7 0C. As was the case for May and July, the warmest August was in 1998 (3.4 0C warmer than LTN). The coolest August occurred in 1995 (1.3C cooler than LTN). Temperatures were coolest at the beginning and end of the six year cycle.

Figure 4. Air temperature (0C at 1.5 m height) measurements for August (mean monthly, growing season (1995-2000) and LTN) at Scott, SK. Monthly values for temperature represent monthly means. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.

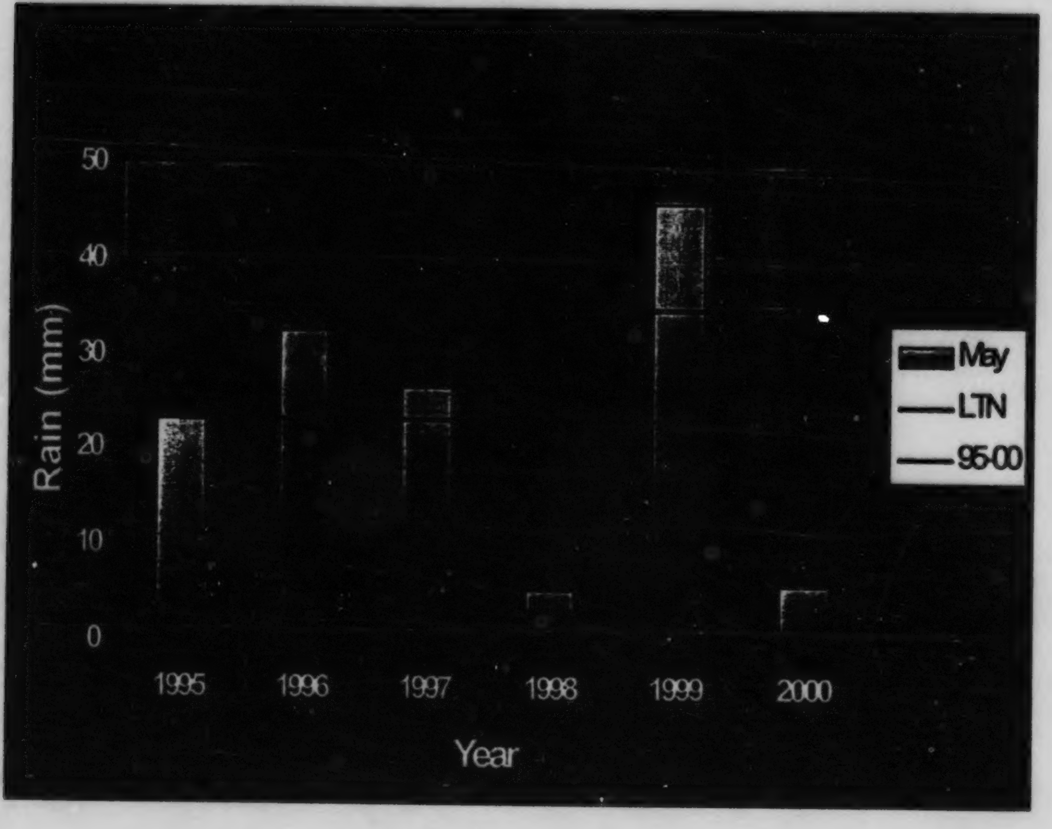


Monthly Precipitation Analysis

May

The May mean total rainfall for 1995-2000 was 23.3 mm compared to the LTN value of 34.7 mm (67.1 % of normal) (Figure 5). The 1995-2000 mean value was affected by unusually low rainfall amounts in 1998 (5.4 mm) and 2000 (6.0 mm). These values are approximately 16.5 % of normal. The wettest May (133.6% of normal) was in 1999 (46.0 mm).

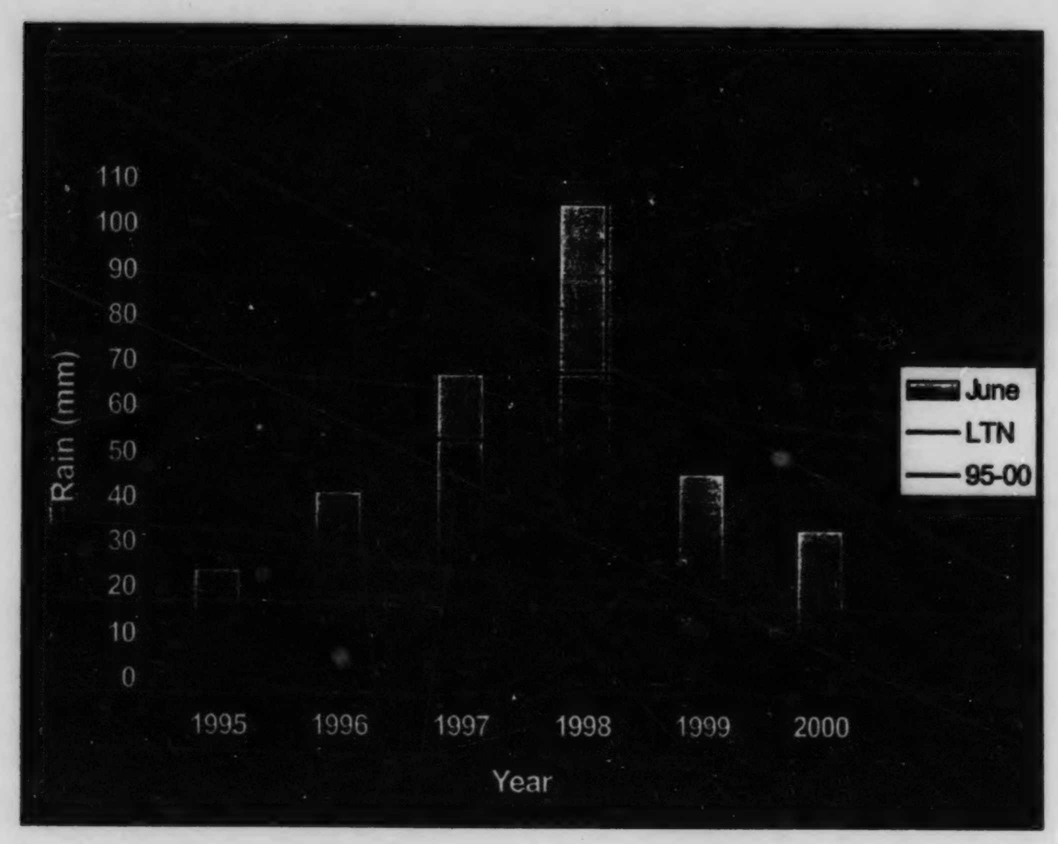
Figure 5. Rainfall (mm) measurements for May (total monthly, growing season (1995-2000) and LTN) at Scott, SK. Monthly values for rainfall represent monthly totals. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



June

Mean June rainfall (1995-2000) amount was 52.8 mm and was 83.9% of normal (67.3 mm) (Figure 6). Mean total rainfall over the first six year cycle was 14.5 mm less than LTN. Only 1997 and 1998 had rainfall greater than LTN. The lowest rainfall amount, 1995, was 23.9 mm (35.5% of normal). June rainfall amounts were lowest at the beginning and end of the six year cycle.

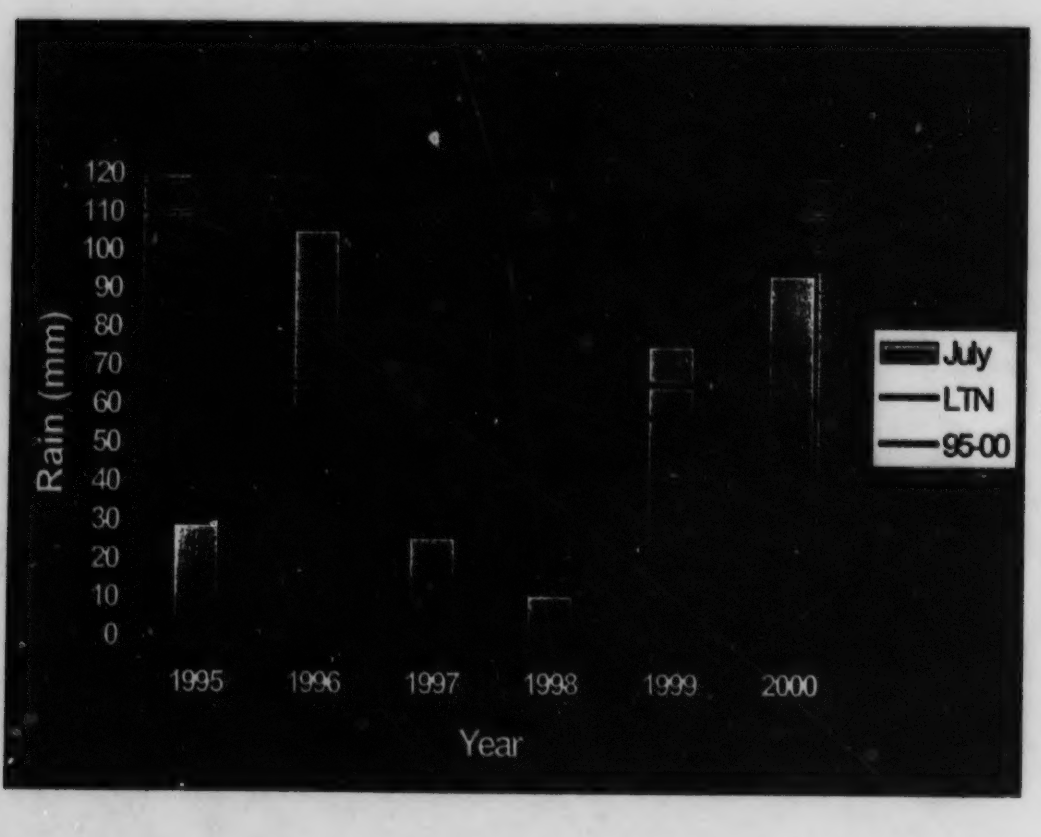
Figure 6. Rainfall (mm) measurements for June (total monthly, growing season (1995-2000) and LTN) at Scott, SK. Monthly values for rainfall represent monthly totals. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



July

Rainfall for 1995-2000 was 87% of normal (57.1 mm) (Figure 7). The LTN was 65.6 mm. The wettest July was in 1996 (105.7 mm, 161.1 % of normal) and the driest July was in 1998 (11.33 mm and 17.3 % of normal).

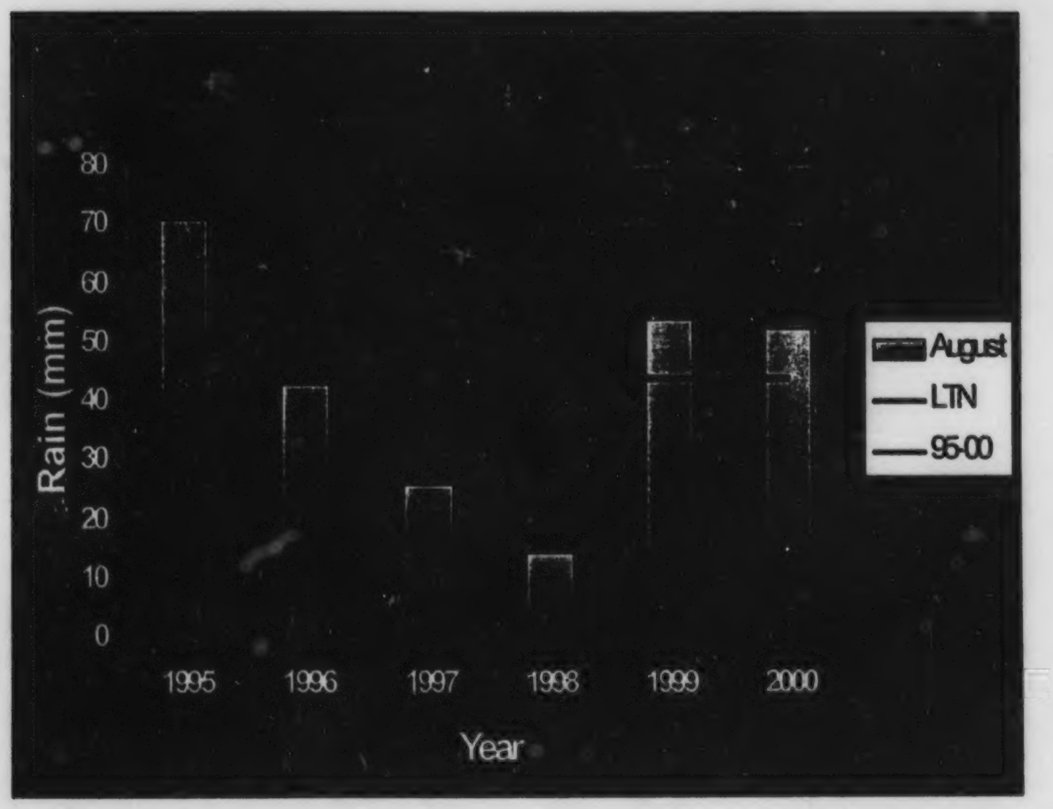
Figure 7. Rainfall (mm) measurements for July (total monthly, growing season (1995-2000) and LTN) at Scott, SK. Monthly values for rainfall represent monthly totals. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



August

Mean total rainfall for 1995-2000 was 43.1 mm (98.6 % of normal) (Figure 8). The greatest amount of rainfall for August occurred in 1995 (70.62 mm, 161.6% of normal) and the driest August occurred in 1998 (14.0 mm, 29.1% of normal). August precipitation amounts decreased from 1995 to 1998 followed by 1999 and 2000 values that were above normal.

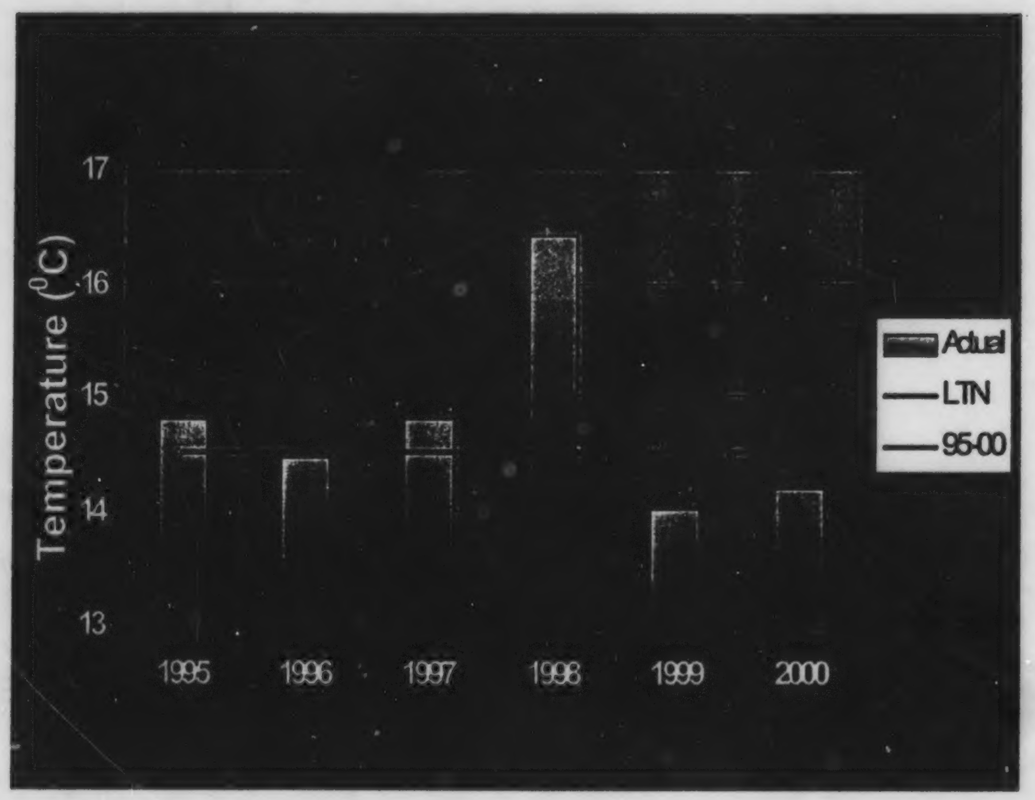
Figure 8. Rainfall (mm) measurements for August (total monthly, growing season (1995-2000) and LTN) at Scott, SK. Monthly values for rainfall represent monthly totals. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



Growing Season Temperature Analysis

The 1995-2000 mean growing season (mean temperature between May 1 and August 31) was 14.9 0C compared to the LTN of 14.5 0C. The warmest season was in 1998 (16.4 0C) and the coolest occurred in 1999 (14.0 0C) (Figure 9). Growing season temperatures were near or above normal between 1995 and 1998, and were below normal for 1999 and 2000. In 1998 May, July and August were warmer than any other year in the 1995-2000 period. In 1999, only August had above normal temperatures.

Figure 9. Growing season air temperature (0C at 1.5 m height) measurements for 1995-2000 (annual growing season, 1995-2000 mean and LTN) at Scott, SK. Annual values for temperature represent mean values for May 1-August 31. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



Growing Season Rainfall Analysis

The 1995-2000 mean total rainfall for the growing season was 176.2 mm compared to the LTN of 211.3 (83.4% of normal)(Figure 10). The wettest growing seasons were in 1996 (221.9 mm) and 1999 (221.0 mm). The driest season was in 1998 (135.7 mm).

Figure 10. Growing season precipitation (mm) measurements for 1995-2000 (annual growing season, 1995-2000 mean and LTN) at Scott, SK. Annual values for rain represent mean total values for May 1- August 31. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.

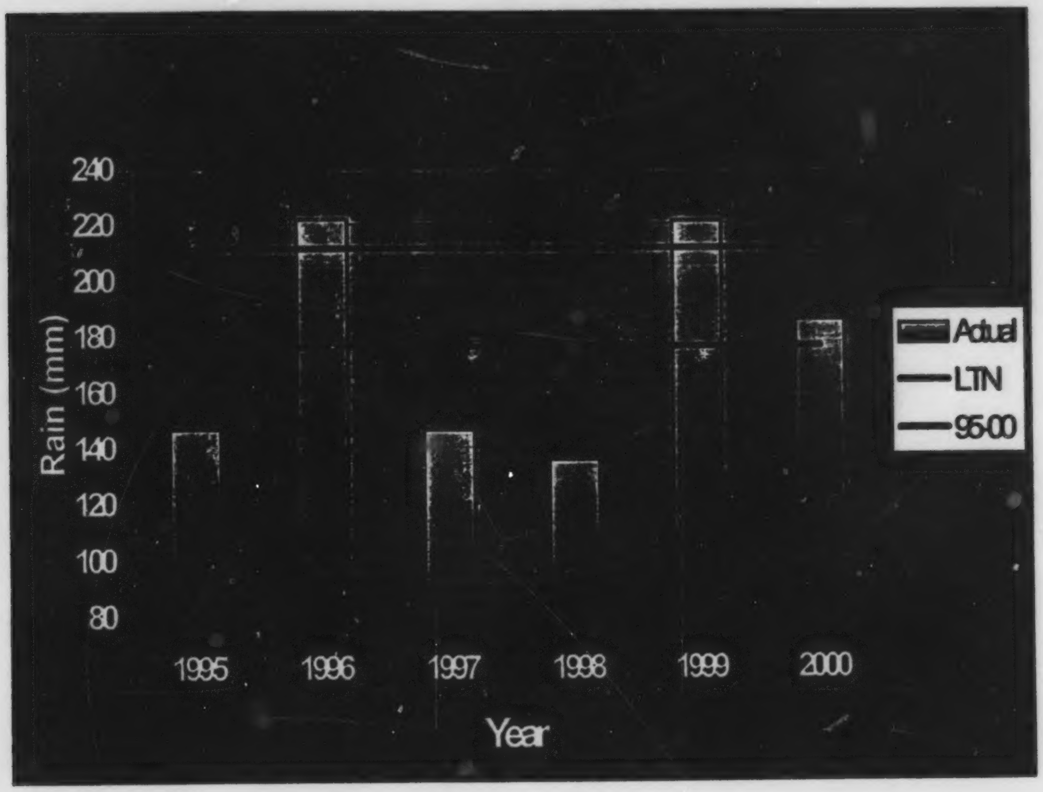
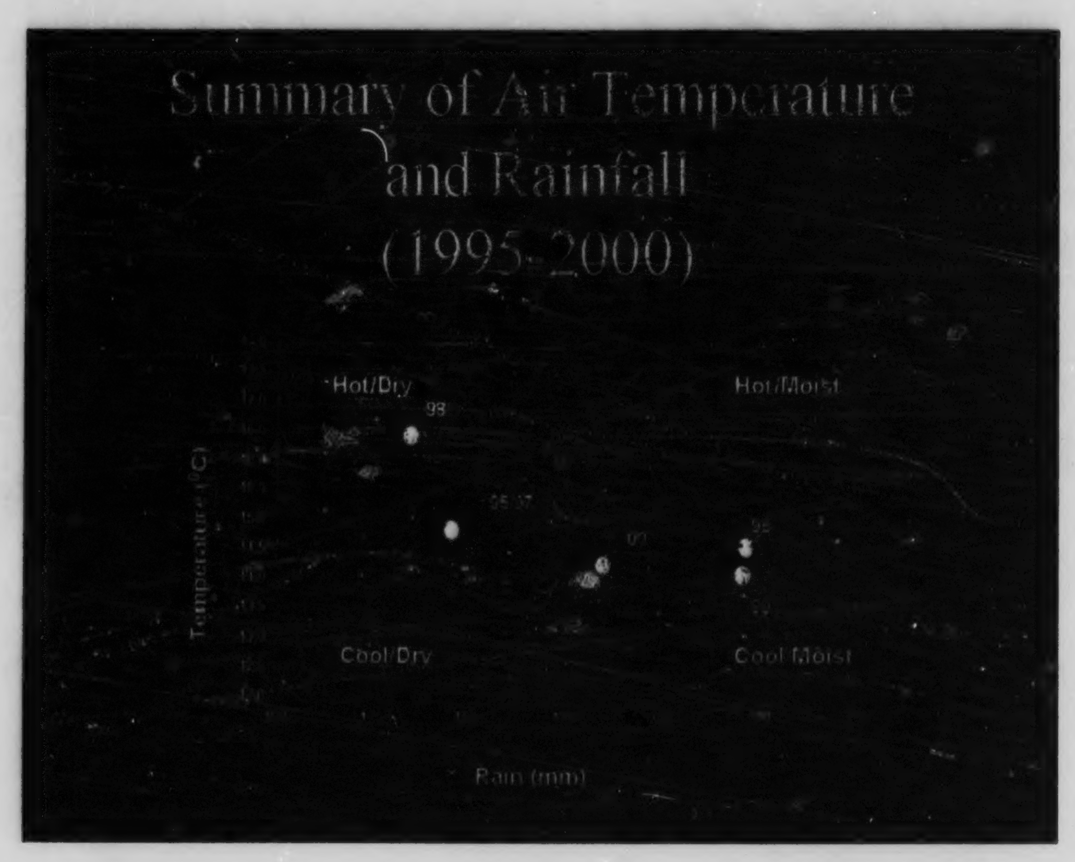


Figure 11 summarizes temperature and rainfall for the 1995-2000 growing seasons. Vertical lines represent mean total precipitation and the horizontal lines represent mean temperature (LTN - red, 1995-2000 - green). The figure shows that the 1995-2000 seasons were dryer and warmer than normal. The 1998 season was much dryer and warmer than normal. The 1996 season had temperature and rainfall values that were closest to normal. Variation in precipitation was greater than temperature variation.

Figure 11. Summary of growing season temperature (0C at 1.5 m height) and precipitation (mm) measurements for 1995-2000 (annual growing season, 1995-2000 mean and LTN) at Scott, SK. Each data point represents annual total rain (mm) and mean temperatue. Long Term Normal (LTN) values based on Environment Canada data for Scott SK. 1961-90.



Alternative Cropping Systems

ACS Long-Term Agro-Ecosystem Research for the Canadian Prairie Ecozone

1994 - 2012

Research Farm
Scott, Saskatchewan

Crop Productivity with Alternative Input Use and Cropping Diversity Strategies

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Rationale

Farmers on the Canadian prairies, are urged to become more diversified in what they produce and to reduce their reliance on fertilizers and pesticides. It is thought that these changes will address food safety and environmental concerns, while conserving the soil resource and providing adequate economic returns. These changes are being proposed in the belief that they will adequately address these issues. However, in most cases, dealing with one of these issues can involve tradeoffs with respect to others.

To date relatively few studies have ben conducted to develop an understanding of how crop production systems function. Most such studies have been based on crop rotations. To enhance our understanding of sustainability, additional system studies are clearly needed.

This research was initiated to investigate how alternative input use and cropping diversity strategies affect sustainability over a 12 -18 year period.

This report details results of crop production and related data on agronomic factors influencing crop production.

Materials and Methods

The study was started in 1994 at the Scott Research Farm. A detailed description of the treatments used and how they were applied is given in the preceding paper by Ulrich *et al.* That information is not repeated here, but a few related pieces of information are provided.

The study is based on three levels of cropping diversity and three levels of input use along with the 6 year cropping sequences as described previously (Table 1).

Table 1. Summary of cropping systems

Crop diversity	Input level	Crop sequence[1]
LOW (low diversity of annual grains)	High	F_T-W-W-F_T-C-W
	Reduced	L_{GM}-W-W-F_C-C-W
	Organic	L_{GM}-W-W-L_{GM}-C-W
DAG (diversified using annual grains)	High	C-R-P-B_M-F_X-W
	Reduced	C-R-P-B_M-F_X-W
	Organic	L_{GM}-W-P-B_M/S_C-S_{CGM}-C
DAP (diversified using annual grains and perennial forages)	High	C-W-B_F-O/B_R&A-H-H
	Reduced	C-W-B_F-O/B_R&A-H-H
	Organic	C-W-B_F-O/B_R&A-H-H

[1] F_T = tillage fallow, W = wheat, C = canola, L_{GM} = lentil green manure, F_C = chemical fallow, P = field pea, B_M = malt barley, B_F = feed barley, S_C = sweet clover, S_{CGM} = sweet clover green manure, R = fall rye, F_X = flax, O = oats, B_R&A = bromegrass-alfalfa, and H = hay.

Some additional information specific to this report is;

- gravimetric soil moisture was determined to 90 cm depth before seeding and after harvest.
- available soil N and P was determined to 60 cm depth on soil samples taken in late October of each year.
- weed biomass was determined on 2 m^2 areas per plot at physiological maturity of the crop.
- grain yield was determined at crop maturity on a 1.2 x 40 m area per plot.
- forage yield was determined on a 1.0 x 40 m area per plot at soft dough stage of oats and 10% bloom of alfalfa.
- protein was determined by near infrared reflectrometry on grain samples and by wet chemistry (kjeldahl) on forages.
- multiple regressions of available water (spring soil water plus growing season precipitation), N supply (soil test N plus fertilizer N) and weeds (weed biomass at crop maturity) with yield were performed in an effort to identify major factors driving yield of individual crops in each system, and their relative importance.

Although the treatments were initiated in 1995, they were all applied on barley stubble. For this reason, yield data from 1995 is not included in this report.

Results and Discussion

Moisture Conditions

For the 5 year period, 1996-2000, 2 years, 1997 and 1998 had below normal growing season precipitation, while 1996 and 1999 were above normal (Table 2). 2000 was only slightly above normal, but soil moisture was relatively high in spring of 2000. The result was that the supply of moisture for crop production was relatively high during 1996, 1999 and 2000, and quite low during 1997 and 1998. There were similarities in relative performance of treatments during years when the supply of moisture was high, that differed from years when the supply of moisture was low. For that reason, results have been summarized across dry and wet years, dry years being 1997 and 1998, wet years being 1996, 1999 and 2000.

Table 2. Growing season precipitation (mm) and spring soil moisture (mm) at Scott during 1996-2000

Month	1996	1997	1998	1999	2000	Long Term[1]	1961-90 normal
May	32	27	5	46	24	36	35
June	41	60	105	43	33	60	67
July	106	26	16	78	94	59	66
August	43	26	14	54	52	45	44
TOTAL	221	138	140	221	203	200	211
Spring soil moisture[2]	151	158	137	139	165		
Total moisture	372	296	277	360	368		

[1] 1910-2000 average.

2 Available spring soil moisture to 90 cm depth averaged over all treatments.

At seeding, differences in soil moisture between input levels or cropping diversity treatments did exist when combined over years, however differences were small (Table 3). There were some significant cropping phase effects (Table 4), with treatments after chemical and tillage fallow having the greatest amounts of stored moisture. Treatments on green manure fallows were sometimes equal to tillage fallow, but on a few occasions they were lower. Treatments that had grown a grain or forage crop the previous year had the least soil moisture (data not shown), with little difference between treatments.

Table 3. Influence of input and cropping diversity on available spring soil moisture (mm) to 90 cm depth (1996-2000 avg)

		Cropping Diversity Level	
Input Level	LOW	DAG	DAP
Organic	151abc*	150ab	152abc
Reduced	158a	150abc	149c
High	155ab	149abc	145c

* values followed by the same letter(s) do not differ significantly from one another [P=0.05]

Table 4. Influence of fallow method and green manure fallow substitutes on subsequent spring soil moisture (mm) to 90 cm depth (1996-2000 avg)[values for Organic and Reduced are averages for 2 phases] in the LOW Diversity system

Organic lentil green manure	156b*
Reduced lentil green manure	158b
Reduced chemical fallow	179a
High tillage fallow	181a

* values followed by the same letter(s) do not differ significantly from one another [P=0.05]

Available Soil Nitrogen

As expected, available soil N was lowest for the organic systems, reflecting that fertilizer N was not applied to these treatments (Table 5). Low soil N with reduced inputs was related to use of direct seeding, which likely reduced mineralization of N from soil organic matter. Rates of N application in reduced input systems were slightly lower than for high inputs, but would not fully account for the differences in soil N. The LOW diversity systems generally had higher soil N than DAG or DAP reflecting N mineralization in the fallow or green manure phases of these systems.

Table 5. Influence of input and cropping diversity on available N in fall (kg/ha) to 60 cm depth (1995-1999 avg)

		Cropping Diversity Level	
Input Level	**LOW**	**DAG**	**DAP**
Organic	49cde*	46ef	41f
Reduced	56bc	51bcde	46ef
High	82a	57b	55bcd

*Values followed by the same letter do not differ (P=0.05)

Crop Production

Wheat grown on fallow (including chemical fallow and green manure) or wheat stubble and barley all showed similar trends when grouped over dry and wet years (Table 6). In all cases, the organic systems were lowest yielding, partly due to increased weed competition, but also largely due to reduced N supply. During dry years, reduced inputs provided yield that was similar to high inputs, but during wet years, high inputs yielded more.

Differences in weed competition between high and reduced systems were relatively small. The observed yield differences would be consistent with differences in available N. In years of below normal moisture, the demand for N was lower, and yields were similar. In wet years when crop demand was greater the reduced systems with less N failed to produce yields equal to the high input systems.

Yield of organic barley was only about half that of reduced and high input barley in dry years. It was anticipated that organic barley would perform well due to the reportedly greater weed competitiveness of barley than other crops. However in the organic DAG system, the crop was under sown to sweet clover, and this likely competed with the crop reducing yield. In the organic DAP system, barley was grown 3 years after an N fixing legume, which may have further reduced available N, particularly N mineralized during the growing season. Such differences would not be readily detected by conventional soil testing in late fall.

Where wheat was grown on canola stubble a somewhat different trend appeared. In dry years, yield was quite low for the high input wheat. It is likely that residues of Edge applied for weed control in the preceding canola crop were causing damage. This damage was only evident in dry years, and only in high input wheat, although the same herbicide treatment was applied to canola in the reduced input system. Portions of some wheat rows showed considerable symptoms while others showed none. Thus this damage may be a result of uneven herbicide distribution due to tillage being applied in one direction only.

In wet years relative yields for the 3 input systems followed a similar pattern to yield on wheat stubble, although the reduced system was still at least equal to high inputs.

Canola was usually low yielding in the organic systems. Weed competition was relatively high in the organic systems, partly because canola would not tolerate post emerge harrowing, a practice that was used extensively in larger seeded organic crops. In addition, organic canola was seeded later as part of the weed control strategy, and *B.rapa* varieties were used, as opposed to *B. napus* in reduced and high systems.
In dry years, high input canola was low yielding, mainly because crop establishment was poor. This was most probably due to the seed bed drying out as a consequence of pre seeding tillage used with high inputs.

Table 6. Yield (kg/ha) of crops in individual cropping phases as influenced by input level during dry (1997 and 1998) and wet (1996,1999,2000) years

Cropping Phase	Input Level	Dry Years	Wet Years
Wheat on fallow	Organic	1402b	2637c
	Reduced	2035a	3399b
	High	2076a	3962a
Wheat on wheat stubble	Organic	1084b	1779c
	Reduced	1518a	2726b
	High	1461a	3266a
Barley	Organic	900b	2352c
	Reduced	1829a	3758b
	High	1781a	3976a
Wheat on canola stubble	Organic	1296b	1866c
	Reduced	1808a	2808b
	High	1296b	3156a
Pea	Organic	828b	2742b
	Reduced	1943a	3325a
	High	2200a	2729b
Canola	Organic	534b	821c
	Reduced	1179a	1496b
	High	700b	1862a
Flax	Reduced	643a	1306a
	High	554a	1292a
Fall Rye	Reduced	1700a	2062a
	High	1555a	1987a
All Forages	Organic	980	1282
	Reduced	1346	1693
	High	1281	1716

Yields for the same cropping phase in the same column followed by the same letter do not differ (P=0.05)

Because pea was able to fix N to meet most of it's needs, it behaved quite differently than other crops. In dry years, high input was highest yielding. Lower pea yield with organic in dry years was associated with delayed seeding, which resulted in the crop flowering during periods of greater climatic stress.

Reduced input pea may have been adversely affected by winter annual weed and volunteer rye growth, that was allowed to remain until just prior to seeding in 1998. This did reduce seed bed moisture, and reduced pea emergence in that one case. During 1997, organic pea was quite weedy because post emerge harrowing was not sufficiently aggressive. Under wet conditions, reduced input pea was higher yielding than either high or organic input pea. It is worth noting that pea can be seeded quite deep. This allowed organic pea to tolerate rather aggressive post emerge harrowing. The result was that weed control in organic pea was almost equal to high or reduced inputs with the one exception as noted above. Results with pea raise an interesting question regarding whether we would be able to boost yield of other crops in reduced input systems simply by increasing N application rates.

Flax was not grown in any of the organic systems. Flax yield did not differ significantly between reduced or high inputs during either dry or wet years (data not shown).

Fall rye was grown on canola stubble in the high and reduced input systems. If residues from Edge affected yield of high input wheat on canola stubble, it is likely that it had at least as large an impact where fall rye was grown. This is a possible explanation for slightly higher yield with reduced than high inputs and both dry and wet conditions although the differences were not statistically significant(data not shown).

Forage yield was highly variable because forages failed to establish adequately in several years. For this reason, it was difficult to distinguish any trends.

Yields for each of the input and diversity systems reflect the composite of individual crop responses. Under dry conditions, the reduced input systems tended to be favored with all diversity systems (Figure 1a). Yield with reduced and high inputs was highest for DAG and lowest for LOW diversity. With organic inputs, DAP was highest yielding and DAG lowest.

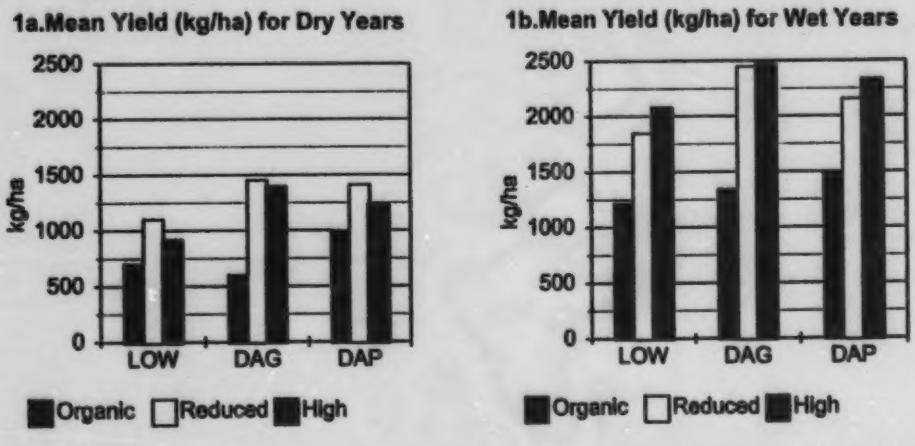

Figure 1. Mean yield for 6 phases of 3 input systems and 3 levels of cropping diversity during dry (a,1997 and 1998) and wet (b, 1996,1999, and 2000) years.

In wet years, yield increased in the order DAP>DAG>LOW for organic, but for reduced and high inputs the relationship was DAG>DAP>LOW (Figure 1b). The general trend for high inputs to provide higher yield than reduced inputs was maintained for LOW and DAP. However with DAG these 2 input systems provided similar yields. This reflects the presence of several crops in the DAG system that performed relatively well with reduced inputs in wet years.

Yield Drivers

Crop yield at harvest is a reflection of a number of crop, crop pest, soil and climatic factors that can either enhance or restrict crop production. Thus yield of any crop is a function of the unique set of conditions under which that crop is grown. Accounting for all of these factors in a study such as this is not possible. However, attempts were made to quantify some factors which were known to potentially have a substantial influence on yield

In an attempt to identify and evaluate the impact of some of these factors, several multiple regressions of yield with the supply of water, and of nitrogen as well as indicators of weed competition were performed. Regressions were only performed on wheat, canola and pea, because the datasets for other crops were too small to show any relationship. It should be noted that these regressions are based on limited data, and examine three only of a number of factors that influence yield. **These relationships should be regarded as preliminary indicators only, and may change substantially as additional data and understanding of the systems is generated.**

The regressions for each crop that best related to yield were as follows;

Wheat Yield [kg/ha] = -3852 + 16.15 water** + 10.62N** -31.98 weeds** adjusted R2 =0.72**
Canola Yield [kg/ha] = -2581+ 8.87 water** + 8.64 N** - 4.04 weeds adjusted R2 = 0.69**
Pea yield [kg/ha] = -3875 + 17.85water** + 11.21 N - 22.41 weeds adjusted R2 = 0.73**
** denotes factors statistical significance at P=0.05

Where water [mm] is available spring soil moisture plus precipitation from 1 May to 31 August, N [kg/ha] equals available soil N plus fertilizer N, and weeds is weed biomass at harvest expressed as % of crop biomass.

[weed biomass as % of crop biomass was used in preference to weed biomass alone as it was less influenced by available water, and was considered to be a better indicator of the degree of competition of weeds with crop].

The regressions suggest that for all three crops, water was an important factor affecting yield. This was probably the major factor explaining yield differences between years. For wheat and canola, nitrogen was also a major factor influencing yield, and it is probable that N deficiency was a major factor contributing to lower yield of these crops in the organic systems. The relationship of pea yield with N was less clear. This was not unexpected since pea is an N fixing crop, and fixation of N by pea was not accounted for in the N factor used in the regression. This likely provides an explanation for the relatively good performance of organic pea in some cases relative to high input pea. Weed competition was related with wheat yield, but showed a less clearly defined relationship with canola and pea. This likely indicates the some of the weaknesses associated with using weed biomass at harvest as an indicator of weed competitiveness with the crop. Several species present in the study matured ahead of the crop, and had shed seed and small leaves prior to crop harvest, making it very difficult to obtain an accurate measure of the total weed biomass produced. The fact that the relationship was stronger for wheat may reflect that larger number of data points for wheat [90] than for canola[54] or pea [18].

These regressions were used to generate crude estimates of yield loss associated with N deficiencies and weed competition for the three crops. (Table 7). These estimates suggest that N deficiencies in both Reduced and High input systems may have had a major influence on wheat and canola yield., while weeds likely only had a major impact on yield of organic wheat, canola and pea.

Table 7. Estimates of yield loss (kg/ha) associated with N deficiencies and weed competition averaged over all 6 years for each input level

Crop	N deficiency relative to High inputs			Weed competition		
	Organic	Reduced	High	Organic	Reduced	High
Wheat (2535)*	674	209	0	100	35	23
Canola (1397)	461	100	0	124	26	23
Pea (2520)	?	?	?	500**	47	60

* Numbers in brackets are mean yield for the High input systems.

** Most of this yield loss occurred in 1997, the average for all other years was only 140 kg/ha

Alternative Cropping Systems

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Potential for Wind Erosion in Alternative Cropping Systems

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Rationale

The objective of this study was to determine the potential for soil erosion in components of cropping systems. Residue cover and aggregate size distribution are two key factors, which affect the potential for wind erosion (Morgan 1986). Current guidelines for residue related to control of wind erosion are from information provided by the Prairie Farm Rehabilitation Administration (1998).

Table 1. Residue cover required for erosion control and critical levels of bare ground (PFRA, 1998).

Wind Erosion	Residue cover (%)	Bare ground (%)[z]
Soil texture		
Medium (loam)	45	55
Fine (clay)	60	40
Coarse (sandy)	75	25

[z] Bare ground calculated from residue cover

Critical values for aggregate size distribution (Table 2) are based on the information from Morgan (1986).

Table 2. Assessments of soil erodibility by wind (after Dolgilevich, Sofronova and Mayevskaya (1973) in Morgan 1986).

% dry stable aggregates < 0.84 mm	<20	20-50	50-70	70-80	>80
Erodibility (t ha^{-1} y^{-1})	<0.5	0.5-1.5	1.5-5	5-15	>15

The Residue Tillage Decision Support System (RTDS) was used to simulate production of crop residues in the Alternative Cropping Systems Study at Scott Saskatchewan. The program includes an empirical equation for decomposition of crop residue, effects of tillage on residue, and costs based on field operations in Western Canada. The program calculates changes in residue mass due to decomposition, based on an equation developed by Douglas and Rickman (1992). In the program, decomposition of residues is based on cumulative degree days (CDD), location of residue at the surface or in soil, in crop or fallow. The Douglas Rickman model has been evaluated for a

number of cereals and broadleaf crops in chemical and tillage fallow systems at the Melfort Research Farm (Moulin et al 1995). Over winter losses of residue are based on coefficients calculated from field data. Decreases in residue due to tillage are calculated with a series of coefficients specific to different implements and residue classes.

Methods

Spatial and Statistical Variability

Data reported in the assessment of spatial variability of soil particle size and electrical conductivity were collected in 1994. Samples and measurements for analysis of aggregate size distribution, conductivity, bulk density, particle size, and saturated hydraulic conductivity were measured for 160 and 176 sample sites per location at Scott and Melfort respectively. All sample sites were in a contiguous block at Scott. Distance between sample sites were varied to provide information on spatial dependence at various lags.

Analytical

Laboratory analyses for particle size distribution, soil moisture, bulk density were conducted at Swift Current, while aggregate size distribution, electrical conductivity and saturated hydraulic conductivity were determined at Melfort. Aggregate size distribution was measured for ~ 2.5 kg samples taken to a 5 cm depth at each location. Gravimetric soil moisture at the time of sampling was also determined. Aggregate fractions were sieved in 8 fractions, >68.8 mm, 68.8 to 38 mm, 38 to 12.7 mm, 12.7 to 7.2 mm, 7.2 to 2.0 mm, 2.0 to 1.3 mm, 1.3 to 0.5 mm, < 0.05 mm, using a Chepil rotary nested sieve. Geometric mean diameter (GMD) and erodible aggregates < 0.84 mm were calculated from a regression of log transformed sieve size (Y) on probit transformed cumulative weight fraction (X). Saturated hydraulic conductivity was measured using the constant head soil core technique.
Soil conductivity readings were collected with a Geonics EM38 at each shallow sample site in the studies. Two sets of readings were taken at each site to determine uniformity, with the second reading at right angles to the first. Measurements in the vertical and horizontal orientation integrate conductivity to 1.5 and 0.75 m respectively.

Statistical

Means, standard deviations and coefficients of variation were calculated for all soil properties measured at Scott. A matrix of Pearson correlation coefficients was generated for soil variables in the study. Probabilities for the coefficients in the study were adjusted with the Bonferroni procedure to compensate for the comparison error rate. Spatial variability of soil variables at Scott was evaluated by plotting contour maps of kriged estimates of soil variables and associated errors. Spatially related variables and related error were plotted using ordinary block (2*2 point) kriging with a spherical model. All data pairs with a minimum lag increment of 10 m were included in the calculation. Each variable was evaluated for spatial dependence and stationarity by calculating semivariograms at angles of 0, 45, 90 and 135 ° with a bandwidth of 22.5 °. Sill and nugget values were determined by fitting a spherical model to the data. Variables were not transformed if significant skewness or kurtosis were identified as normality is not required for the calculation of the semivariogram. Spatial variability of soil variables at Scott was evaluated by calculating the semivariograms and plotting contour maps of kriged estimates of soil variables and associated errors.

Potential for Wind Erosion

Data reported in the analysis of the potential for wind erosion were collected in 1997. Calculations of residue mass and cover are based on tillage operations conducted in 1996 in at or near seeding in the second and sixth phases of each treatment. In 1996, fallow treatments in organic and high input systems were tilled in the fall and spring with a heavy-duty cultivator. Plots were prepared for seeding in organic and high input systems with a heavy-duty cultivator with mounted tine harrows followed by a heavy-duty cultivator. Fallow treatments were not tilled in reduced input systems. Plots were direct seeded in reduced input systems.

Analytical

Aggregates, bulk density and soil moisture were sampled from the 0 to 5 cm depth increment shortly after seeding in 1997. Aggregate samples weighing approximately 2.5 kg were dry sieved with a rotary sieve. Bulk density and oven dry soil moisture were measured in a soil core taken at the same time. Samples were collected from the second and sixth phase of all treatments. Aggregate size distribution was measured for ~ 2.5 kg samples taken to a 5 cm depth at each location. Gravimetric soil moisture at the time of sampling was also determined. Aggregate fractions were sieved in 8 fractions, >68.8 mm, 68.8 to 38 mm, 38 to 12.7 mm, 12.7 to 7.2 mm, 7.2 to 2.0 mm, 2.0 to 1.3 mm, 1.3 to 0.5 mm, < 0.05 mm, using a Chepil rotary nested sieve. Crop residue cover was measured in two m2 quadrats per plot.

Statistical

Statistical analyses were conducted for the soil and crop variables in each year of the study. A general linear model was calculated for phases 2 and 6 of the treatments with diversity nested within input. Error bars represent one least significant difference for significant effects specified in the appendices. Data were analyzed using analysis of variance for a split plot design using Genstat 5 version 4.2. Significant treatment effects ($P < 0.05$) were evaluated using least significant differences.

Simulation

Residue cover was simulated with inputs based on harvest index, decomposition with the Douglas-Rickman Equation and tillage coefficients as described previously (Moulin et al 1995). Residue mass was converted to cover with the equation developed by Gregory (1982). Tillage operations and dates are based on those for the study in 1996 while air temperatures are the 30 means for air temperature at the Scott meteorological station.

Results and Discussion

Spatial And Statistical Variability Of Soil Variables

Bulk density and particle size distribution were relatively uniform at the site in contrast to aggregate size distribution, hydraulic conductivity, geometric mean diameter and erodible fraction which were all highly variable (Table 3). Frequency distributions of EM 38 readings, saturated hydraulic conductivity, sand content, geometric mean diameter, and erodible fraction were significantly skewed . All variables had significant kurtotic distributions.

Table 3. Statistical properties of soil variables at Scott.

Variable	Mean	Standard Deviation	Coefficient of Variation (%)
Bulk Density 0 - 3 cm, (Mg m^{-3})	1.16	0.08	7.6
Bulk Density 3 - 6 cm, (Mg m^{-3})	1.33	0.09	6.6
Sand (%)	69.6	5.1	7.3
Silt (%)	20.5	4.0	2.0
Clay (%)	9.9	3.2	3.2
Saturated Hydraulic Conductivity (m/s) * 10^{-}	6.3	5.8	92.8
Erodible Aggregate Fraction < 0.84 mm (%)	16.1	6.5	40.2
Geometric Mean Diameter (mm)	23.2	39.4	169.5

Soil Texture and Physical Properties

Much of the variability in soil properties was correlated with soil texture. Moisture holding capacity, erodible fraction, bulk density and conductivity were significantly correlated with sand content. The proportion of erodible aggregates increased with sand content while moisture content decreased. Geometric mean diameter (GMD) of aggregates was significantly correlated with silt content of the soil although the correlation coefficient (0.314) was low(Table 4). Electrical conductivity varied from 16 to 36 mS m-1 for the Scott site, at levels which are considered non saline.

Table 4. Correlation coefficient and significance (probability) matrix for soil variables at Scott.

Variable	EMv	EMh	MS	KS	BD 0-3	BD 3-6	Sand	Silt	Clay
EM 38 vertical (EMv)									
EM 38 Horizontal (EMh)									
Moisture at Sampling (MS)									
Saturated Hydraulic Conductivity (KS)									
Bulk Density 0- 3 cm (BD0-3)									
Bulk Density 3- 6 cm (BD3-6)			-0.31 (1.7)						
Sand	-0.33 (0.59)		-0.34 (0.2)		0.33 (0.4)				
Silt			0.32 (1.0)		-0.52 (<0.01)		-0.77 (<0.01)		
Clay							-0.61 (<0.01)		
Geometric Mean Diameter (GMD)								0.31 (1.3)	
Erodible Fraction (<0.84mm) (EF)							0.44 (<0.01)		

Spatial Variability of Soil Variables

Sand fraction varied considerably across the area with several high values near 80% in the north west corner of the field. These high points reflect the existence of a sandy knoll. Spatial error associated with the estimate of sand fraction was between 2 and 2.5 % . The erodible aggregate fraction <0.84 mm was also high at the same locations in the field as the sand fraction. Soil properties are not related to elevation (Figure 4).

Table 5. Variables for semivariograms of spatial properties.

Variable	Spatial Dependence	Sill	Range	Nugget Value
EM 38 horizontal	Yes	43	80	10
EM 38 vertical	Yes	30	180	7
Saturated Hydraulic Conductivity	Yes	30	75	7
Bulk Density 0-3 cm	No			
Bulk Density 3-6 cm	No			
Sand (%)	Yes	19	140	5
Silt (%)	Yes	14	80	5
Clay (%)	Yes	10	100	3.5
Geometric Mean Diameter	Yes	750	50	525
Erodible Fraction (<0.84 mm)	Yes	32	100	18

Potential for Wind Erosion

The potential for erosion was significantly higher in spring following fallow in fallow wheat-wheat-fallow-canola-wheat compared to other rotations. Potential was lowest in the second phase with fall rye in canola-fall rye-pea-barley-flax-wheat. High input systems following canola in the sixth phase of fallow-wheat-wheat-fallow-canola-wheat had higher residue cover than organic systems following crop due to increased production. These effects were attributed to the effect of tillage and the relative levels of productivity in the systems. Spring and fall tillage in organic systems reduced the amount of residue compared to reduced input systems.

The experimental data also reflected the relative differences calculated with the Douglas-Rickman equation and tillage coefficients. Bare ground observed in 1997 varied from those predicted for input and diversity treatments, as 30-year means of air temperature were used in the simulations.

High amounts of aggregates in the erodible fraction will also contribute to significant levels of soil erosion. Inclusion of fall rye in rotation for diverse annual systems significantly decreases the potential for erosion.

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Economics of Alternative Input Use and Crop Diversity Strategies in the Dark Brown Soil Zone of Saskatchewan

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Rationale

Declining commodity prices coupled with rapidly rising input costs are causing many producers in western Canada to question the merits of conventional high-input agricultural production systems. In response, producers have become increasingly interested in extending and diversifying their cropping systems, and in adopting low-input and organic management practices.

The objective of this study was to compare production costs, economic returns, and riskiness of nine cropping systems, representing three levels of input usage (high, reduced, and organic), and three levels of cropping diversity (low crop diversity, diversified with annual grains, and diversified with annual grains and forages). The paper draws on data from the first 6 years of a long-term field experiment being conducted in the Dark Brown soil zone at the Scott Experimental Farm.

Methods

The economic analysis follows methods used previously by Zentner et al. (1992) and Zentner and Campbell (1988). Spreadsheet programs were developed to determine and compare annual total and unit costs of production, amount and seasonal distribution of resource needs (e.g., fertilizer, herbicide, fuel, machine repair, labor, specialized equipment needs), level of gross and net returns (i.e., income remaining after paying for all cash costs, plus labor and overhead costs for machines and buildings), and riskiness (income variability) for each cropping system. A total of nine cropping systems (all 6 years in length), representing three levels of input usage (i.e., "high" which uses recommended rates of fertilizers and pesticides as required; "reduced" which uses reduced inputs of fertilizer, pesticides, and fuel; and "organic" which uses non-chemical pest control methods and legume green manure) and three levels of cropping diversity (i.e., low diversity (LOW), diversified using annual grains (DAG), diversified using annual grains and perennial forages (DAP)), were evaluated using data from the 1996 to 2000 period (Table 1). Data from the initial year of the experiment (i.e., 1995) were excluded from the analysis because all crops were not yet in proper sequence and thus would not reflect true treatment effects.

The experimental data were extrapolated to the farm-level using a representative farm of 777 ha and a typical complement of machinery for each cropping system. Costs for inputs were held constant at their 2000 levels (Table 2 and Table 3) (Saskatchewan Agriculture and Food, 2000). Products were valued at their respective 1996/97 - 1998/99 average farm-gate prices (net of elevation, transportation, and storage costs) (Table 4). Wheat prices were adjusted for protein concentrations obtained in the respective treatments using the 1996/97 - 1998/99 average protein price premium schedule as established by the Canadian Wheat Board. The analysis was repeated for three organic grain price scenarios: (i) price premiums received on 50% of the organically grown grains produced (reflects a situation where one-half of the organic production is sold in the organic market and the other half is sold in the conventional or commercial market), (ii) no price premiums over conventionally grown grains (reflects a situation faced by organic producers during the certification period), and (iii) price premiums received on 100% of the organically grown grains produced (reflects a situation where all organic production is sold in the organic market). Participation in the Canada/Saskatchewan all-risk crop insurance program was assumed for all treatments using the 70% yield coverage option for all cereal, oilseed, and pulse crops. Forage was assumed to be uninsured. Premium rates and payout criteria for the respective conventionally and organically grown crops in Risk Area #20 were assumed (Saskatchewan Crop Insurance Corporation, 2000a,b).

Table 1. Summary of cropping systems

Crop Diversity	Input Level	Crop Sequence[1]
LOW (low diversity of annual grains)	High	F_T-W-W-F_T-C-W
	Reduced	L_{GM}-W-W-F_C-C-W
	Organic	L_{GM}-W-W-L_{GM}-C-W
DAG (diversified using annual grains)	High	C-R-P-B_M-F_X-W
	Reduced	C-R-P-B_M-F_X-W
	Organic	L_{GM}-W-P-B_M/S_C-S_{CGM}-C
DAP (diversified using annual grains and perennial forages)	High	C-W-B_F-O/B_R&A-H-H
	Reduced	C-W-B_F-O/B_R&A-H-H
	Organic	C-W-B_F-O/B_R&A-H-H

[1] F_T = tillage fallow, W = wheat, C = canola, L_{GM} = lentil green manure, F_C = chemical fallow, P = field pea, B_M = malt barley, B_F = feed barley, S_C = sweet clover, S_{CGM} = sweet clover green manure, R = fall rye, F_X = flax, O = oats, B_R&A = bromegrass-alfalfa, and H = hay.

All findings were expressed on per hectare basis for the complete cropping systems, which includes the costs and returns for all phases or components of each treatment.

Table 2. Selected farm input costs

Pesticides	Cost ($)	Unit
2,4-D	4.55	litre
Achieve DG	162.00	kg
Assure II	82.50	litre
Avadex BW	2.53	kg
Banvel	32.90	litre
Buctril M	15.94	litre
Dyvel DS	12.70	litre
Edge	1.96	kg
Lontrel	137.05	litre
Mataven	7.00	litre
MCPA Amine	6.25	litre
Muster	1.87	gram
Sodium Salt	4.50	litre
Poast	38.19	litre
Reglone	22.00	litre
Roundup	8.99	litre
Rustler	5.99	litre
Sencor	63.70	litre
Tropotox Plus	11.83	litre
Lorsban 4E	15.62	litre
Tilt	67.80	litre
Decis	129.30	litre
Seed costs		
Alfalfa	5.52	kg
Bromegrass	3.50	kg
Sweet clover	2.95	kg
Indianhead black lentil	0.55	kg
Seed treatments		
Premiere Plus	50.71	litre
JumpStart	2.09	gram
Vitavax RS Flowable	65.63	litre
Vitavax Dual	36.66	litre
Vitavax Powder	34.66	litre
Seed inoculants		
Pea	0.05	kg seed
Lentil	0.08	kg seed
Alfalfa	0.22	kg seed
Sweet clover	0.22	kg seed
Fertilizers		
12-51-0	0.36	kg
46-0-0	0.35	kg
34-0-0	0.33	kg
Fuel		
Gas	0.55	litre
Diesel	0.52	litre

Table 3. Selected field operations and other related costs

Field Operation	Cost ($ ha^{-1})
Combine	34.02*
Haul grain	11.59*
Round bale	22.36*
Haul bales	10.11*
Broadcast	5.32
Double disk press drill	17.84
Field cultivator	8.19
Harrow	5.40
Harrow packer	7.66
Harrow packer & harrow	9.72
Haybine	27.92
Heavy duty cultivator	9.52
Heavy duty cultivator & harrow packer	15.68
Heavy duty cultivator with tine harrows	10.64
Heavy duty cultivator with tine harrow & harrow packer	16.80
Heavy duty cultivator with trailing rodweeder	10.92
Heavy harrow	3.34
Hoe drill	19.22
Land roller	5.43
Manure application	20.97
Medium duty cultivator	8.19
Medium duty cultivator with tine harrows	9.31
Medium duty cultivator with trailed rod & harrows	11.81
Cultivator with spikes	9.52
Rodweeder	7.48
Swath	9.21
Sprayer	6.40
Haul water	0.91
Other related costs	
Interest rate	8.00 (%)
Miscellaneous	11.68
Land taxes	10.85
Labor	9.00 ($ hr^{-1})

*Based on 2000 kg ha^{-1} yield.

Table 4. 1996/97 - 1998/99 average net farm prices ($ t^{-1}) for conventional and organically grown crops

Crop (% Protein)	Conventional	Organic
Wheat (<11.99%) - base	146.17	261.67
Wheat (12.0 to 12.499%)	149.87	265.37
Wheat (12.5 to 12.999%)	153.47	268.97
Wheat (13.0 to 13.499%)	157.17	272.67
Wheat (13.5 to 13.999%)	162.17	277.67
Wheat (14.0 to 14.499%)	167.17	282.67
Wheat (14.5 to 14.999%)	173.17	288.67
Wheat (15.0% or more)	179.17	294.67
Barley – feed	99.09	145.40
Barley – malt	147.06	246.00
Rye	93.15	193.00
Oats	96.82	217.00
Canola	361.19	640.00
Flax	314.45	697.00
Pea	184.67	350.67
Hay (dry matter basis)	82.65	82.65

Source: M. Gimby, Saskatchewan Research Council

Results and Discussion

Overall Annual Economic Performance

The annual economic performance of the cropping systems varied greatly among years (Table 5), largely reflecting the effects of growing season weather conditions on crop yields and grain quality. Gross and net returns (when averaged over cropping treatments) were highest in 1999 and intermediate in 1996 and 2000 when precipitation was above normal, and lowest in the drier years of 1997 and 1998. In contrast, average total costs were relatively similar among study years.

Table 5. Mean annual economic performance of cropping systems (price premiums received on 50% of organically grown grains) ($ ha^{-1})

Economic Parameter	1996	1997	1998	1999	2000
Gross Returns	332	252	208	412	327
Total Costs	189	177	176	182	218
Net Costs	143	75	32	230	109

Economic Performance by Crop Diversity and Input Level

Price Premiums for 50% of Organically Grown Grains

Gross returns for the nine cropping systems averaged $230 ha^{-1} during the dry years and $357 (or 55% more) during the wet years (Table 6). In dry years, gross returns (averaged over Input Levels) were highest and about similar for the DAG and LOW Crop Diversity treatments ($249 ha^{-1}), and lowest for DAP (23% less). Alternatively, when averaged over Crop Diversity levels, gross returns were highest for the Reduced Input treatments ($248 ha^{-1}), intermediate for High Input (7% less), and lowest for Organic Input treatments (15% less). Overall, the cropping systems that provided the highest gross returns during dry years were DAG with High Input and DAG with Reduced Input ($283 ha^{-1}), and the cropping system that provided the lowest gross return was DAP with Organic Input (36% less). In contrast, during wet years, gross returns (averaged over Input Levels) were highest for DAG ($427 ha^{-1}), intermediate for LOW (13% less), and lowest for DAP (36% less); when averaged over Crop Diversity levels, they were highest for High Input ($398 ha^{-1}), intermediate for Reduced Input (11% less), and lowest for Organic Input (20% less). Thus the cropping system with the highest gross returns during wet years was DAG with High Input, and the system with the lowest gross return was DAP with Organic Input, in part reflecting the lack of organic price premiums for forage hay. When averaged over the 5 study years (1996–2000), the ranking of gross return were for the treatments were similar as for the wet years.

Total production costs over the dry years averaged between $137 and $219 ha^{-1}, and were lowest for the DAP and for the Organic Input treatments, and highest for DAG and the High Input treatments (Table 6). The DAG treatments required the highest expenditure for purchased inputs ($214 ha^{-1}) (Table 7). Expenditures for DAP treatments averaged 21% lower ($44 ha^{-1} less) and LOW treatments averaged 16% lower (or $34 ha^{-1} less) than for DAG. The resource categories most affected by changes in Crop Diversity levels were seed, fertilizer, chemicals, and machinery overhead. Seed costs (including seed treatments) accounted for about 14%, fertilizers 10%, chemicals 12%, and machinery overhead for 26% of the respective total costs for each Crop Diversity treatment.

Total production costs also varied considerably among the Input Level treatments (Table 8). Total expenditures for Organic Input treatments averaged 21% less (or $44 ha^{-1} lower) than for High Input and Reduced Input treatments. The largest differences in expenditures were for fertilizer and chemical inputs which were not used by Organic Input treatments, and for (most) seed costs which were higher for Organic Input treatments because of their higher market value. Expenditures for machinery operation and ownership were generally similar for the High Input and Organic Input treatments, and lowest for the Reduced Input treatments (about 20% less).

Table 6. Effect of crop diversity and input level in dry years (1997 and 1998), wet years (1996, 1999 and 2000), and overall on costs and returns for cropping systems - Price premiums received on 50% of organically grown grains ($ ha^{-1})

Dry Years		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	219	283	189	231
	Total Cost	175	219	176	190
	Net Return	44	64	14	41
Reduced	Gross Return	260	282	202	248
	Total Cost	174	203	163	180
	Net Return	86	79	39	68
Organic	Gross Return	260	191	181	211
	Total Cost	169	172	137	159
	Net Return	91	19	44	52
Mean Gross Return		246	252	191	230
Mean Total Cost		173	198	159	177
Mean Net Return		74	54	32	53

Wet Years		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	409	476	308	398
	Total Cost	196	259	192	216
	Net Return	213	217	116	182
Reduced	Gross Return	348	443	270	354
	Total Cost	196	248	196	213
	Net Return	153	195	74	142
Organic	Gross Return	355	363	239	319
	Total Cost	163	167	147	159
	Net Return	192	195	93	160
Mean Gross Return		371	427	272	357
Mean Total Cost		185	225	178	196
Mean Net Return		186	204	94	161

5 Year Mean		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	333	399	260	331
	Total Cost	187	243	186	205
	Net Return	145	156	75	125
Reduced	Gross Return	313	379	243	312
	Total Cost	187	230	183	200
	Net Return	126	149	60	112
Organic	Gross Return	317	294	216	276
	Total Cost	165	169	143	159
	Net Return	152	125	73	117
Mean Gross Return		321	357	240	306
Mean Total Cost		180	214	170	188
Mean Net Return		141	144	69	118

Table 7. Effect of crop diversity on 5-year (1996-2000) average production costs - Price premiums received on 50% of organically grown grains (\$ ha^{-1})

5 Year Mean	Crop Diversity			
Resource	LOW	DAG	DAP	Mean
Oil, lube and fuel	16	17	15	16
Labor	7	8	7	7
Machinery repairs	15	17	14	15
Machinery overhead	48	54	42	48
Chemicals	21	30	16	22
Fertilizers	17	24	19	20
Seed	23	30	25	26
Crop ins. premium	5	5	3	4
Miscellaneous	12	12	12	12
Taxes	11	11	11	11
Interest	5	6	5	5
Total Cost	180	214	170	188

Table 8. Effect of crop diversity on 5-year (1996-2000) average production costs - Price premiums received on 50% of organically grown grains (\$ ha^{-1})

5 Year Mean	Input Level			
Resource	High	Reduced	Organic	Mean
Oil, lube and fuel	18	11	19	16
Labor	8	6	8	7
Machinery repairs	17	14	15	15
Machinery overhead	50	43	51	48
Chemicals	32	35	0	22
Fertilizers	29	31	0	20
Seed	18	26	34	26
Crop ins. premium	4	4	4	4
Miscellaneous	12	12	12	12
Taxes	11	11	11	11
Interest	6	6	4	5
Total Cost	205	200	159	188

The cropping system which earned the highest average net return during dry years was LOW with Organic Input (\$91 ha^{-1}), followed closely by LOW with Reduced Input (5% less) and DAG with Reduced Input (13% less) (Table 6). The cropping system with the lowest net returns during dry years was DAP with High Input management. In contrast, the most profitable cropping systems during wet years was DAG with High Input management (\$217 ha^{-1}), followed by LOW with High Input and DAG with Reduced or Organic Input management (10% less); the poorest performing system was DAP with Reduced Input.

Based on the 5-years of results and the assumption that 50% of the organically grown grains received price premiums, the most profitable cropping systems were LOW with Organic Input, and DAG with High Input or with Reduced Input (Table 6).

No Price Premiums for Organically Grown Grains

Under the assumption of no price premiums, which would be typical of new organic producers who have not yet completed the certification period, the relative profitability of the Organic Input treatments were substantially reduced (Table 9). Net returns for the organically managed LOW, DAG, and DAP treatments declined by an average of \$61, \$43, and \$35 ha^{-1}, respectively, in dry years, and by \$112, \$100, and \$54 ha^{-1} in wet years (compared to the 50% price premium scenario). The most profitable cropping systems were LOW and DAG with Reduced Input management in dry years, and in wet years it was these same two Crop Diversity systems but with High Input management.

Based on the 5-year average performance under the assumption of no price premiums for organically grown grains, the most profitable cropping systems were DAG with High Input and Reduced Input management, with the LOW system using High Input management ranking second highest (Table 9).

Price Premiums For 100% of Organically Grown Grains

Under the assumption that all grains grown using organic management methods received the full price premiums, the relative profitability of the Organic Input treatments were increased substantially (Table 10). Net returns for organically managed LOW, DAG, and DAP treatments increased (relative to the 50% price premium scenario) by a further \$28 to \$44 ha^{-1} in dry years and by \$44 to \$88 ha^{-1} in wet years, with the increases being smallest for the DAP treatments. The most profitable cropping system was LOW with Organic Input management in dry years, and DAG with Organic Input management in wet years. Overall, the most profitable cropping system under this price scenario was LOW with Organic Input management, followed by DAG with Organic Input management (12% less).

Riskiness

When choosing among cropping systems, producers are often faced with a trade-off between increases in annual net returns and increases in income variability or financial risk. As producers become increasingly risk averse, they tend to choose cropping systems that display lower income variability. The final choice or selection of a cropping system depends upon the risk attitudes of individual producers (their willingness to gamble), expectations on product prices and input costs, and the nature of the distributions of probable net returns that can be earned with each cropping system. Under the conditions of this study, net income variability (or risk) tended to be lowest for DAG, intermediate for LOW, and highest for the DAP cropping systems (Table 11). With one exception, income variability tended to be lowest with Organic Input < Reduced Input < High Input. Overall, the cropping system that displayed the lowest income variability was DAG with Reduced Input management.

Table 9. Effect of crop diversity and input level in dry years (1997 and 1998), wet years (1996, 1999 and 2000), and overall on costs and returns for cropping systems - No price premiums for organically grown grains ($ ha^{-1})

Dry Years		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	219	283	189	231
	Total Cost	175	219	176	190
	Net Return	44	64	14	41
Reduced	Gross Return	260	282	202	248
	Total Cost	174	203	163	180
	Net Return	86	79	39	68
Organic	Gross Return	192	141	143	159
	Total Cost	162	166	134	154
	Net Return	30	-24	9	5
Mean Gross Return		224	236	178	213
Mean Total Cost		170	196	158	175
Mean Net Return		53	40	20	38

Wet Years		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	409	476	308	398
	Total Cost	196	259	192	216
	Net Return	213	217	116	182
Reduced	Gross Return	348	443	270	354
	Total Cost	196	248	196	213
	Net Return	153	195	74	142
Organic	Gross Return	236	255	183	225
	Total Cost	156	160	144	153
	Net Return	80	95	39	71
Mean Gross Return		331	392	254	325
Mean Total Cost		183	222	177	194
Mean Net Return		148	170	77	131

5 Year Mean		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	333	399	260	331
	Total Cost	187	243	186	205
	Net Return	145	156	75	125
Reduced	Gross Return	313	379	243	312
	Total Cost	187	230	183	200
	Net Return	126	149	60	112
Organic	Gross Return	219	210	167	198
	Total Cost	159	162	140	154
	Net Return	60	48	27	44
Mean Gross Return		288	329	223	280
Mean Total Cost		178	212	169	186
Mean Net Return		110	117	54	94

Table 10. Effect of crop diversity and input level in dry years (1997 and 1998), wet years (1996, 1999 and 2000), and overall on costs and returns for cropping systems - Price premiums received on 100% of organically grown grains ($ ha^{-1})

Dry Years		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	219	283	189	231
	Total Cost	175	219	176	190
	Net Return	44	64	14	41
Reduced	Gross Return	260	282	202	248
	Total Cost	174	203	163	180
	Net Return	86	79	39	68
Organic	Gross Return	308	234	211	251
	Total Cost	173	178	139	163
	Net Return	135	55	72	88
Mean Gross Return		262	266	201	243
Mean Total Cost		174	200	159	178
Mean Net Return		88	66	42	65

Wet Years		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	409	476	308	398
	Total Cost	196	259	192	216
	Net Return	213	217	116	182
Reduced	Gross Return	348	443	270	354
	Total Cost	196	248	196	213
	Net Return	153	195	74	142
Organic	Gross Return	439	457	286	394
	Total Cost	167	174	149	163
	Net Return	272	283	137	231
Mean Gross Return		399	459	288	382
Mean Total Cost		186	227	179	197
Mean Net Return		213	232	109	185

5 Year Mean		Crop Diversity			
Input Level	Parameter	LOW	DAG	DAP	Mean
High	Gross Return	333	399	260	331
	Total Cost	187	243	186	205
	Net Return	145	156	75	125
Reduced	Gross Return	313	379	243	312
	Total Cost	187	230	183	200
	Net Return	126	149	60	112
Organic	Gross Return	387	368	256	337
	Total Cost	169	176	145	163
	Net Return	218	192	111	174
Mean Gross Return		344	382	253	326
Mean Total Cost		181	216	171	190
Mean Net Return		163	166	82	136

Table 11. Index of annual variability in net returns for cropping systems – Price premiums received on 50% of organically grown grains

Input/Crop Diversity	LOW	DAG	DAP
High	164	113	217
Reduced	155	98	208
Organic	134	195	194

Conclusions

As expected with the limited dataset, the economic performance of the nine production systems varied among years, and depended greatly on the eligible quantities of product sold into the organic market (or the price premiums received for organically grown grains). Based on the five years of results reported, the findings suggest that the Crop Diversity treatment, DAG, is most profitable under wet conditions despite its higher costs of production, and LOW is best under dry conditions. The DAP system was not economically competitive under the price assumptions used in this analysis, in part due to the lack of a direct price premium for organically grown forage hay. With respect to the Input Level treatments, the use of High Input management was more profitable in wet years when the response to management inputs (e.g., fertilizers and pesticides) is greatest due to the favorable growing conditions. The Reduced Input management treatments, with its lower cash outlay requirements, performed well in dry years, and may represent a good risk management strategy for drought situations. The use of Organic Input management was more profitable than the High Input or Reduced Input management systems under the 1996/97 - 1998/99 price premiums levels that existed for organic grains. These findings bode well for organic producers who are fully certified and are able to sell most or all of their production into organic markets and can capture the full price premiums. However, the findings also suggest that for new organic producers farm incomes may be lower during the three-year certification period.

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Effects of Input Level and Crop Diversity on Energy Use Efficiency of Cropping Systems in the Dark Brown Soil Zone

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Rationale

Declining commodity prices coupled with rapidly rising input costs are causing many producers in western Canada to question the merits of conventional high-input agricultural production systems. In response, producers have become increasingly interested in extending and diversifying their cropping systems, and in adopting low-input and organic management practices. However, little is known about the impacts of these land use changes on the requirements for non-renewable energy inputs and energy use efficiency.

Methods

Experimental Data

- Initiated in 1995 in the Dark Brown soil zone at the Scott Experimental Farm.
- Data from the intial year (i.e. 1995) are excluded from the analysis because all crops were not yet in proper sequence and thus would not refelct the true treatment effects.
- Crop Rotations:

Crop diversity	Input level	Crop sequence[1]
LOW (low diversity of annual grains)	High	F_T-W-W-F_T-C-W
	Reduced	L_{GM}-W-W-F_C-C-W
	Organic	L_{GM}-W-W-L_{GM}-C-W
DAG (diversified using annual grains)	High	C-R-P-B_M-F_X-W
	Reduced	C-R-P-B_M-F_X-W
	Organic	L_{GM}-W-P-B_M/S_C-S_{CGM}-C
DAP (diversified using annual grains and perennial forages)	High	C-W-B_F-O/B_R&A-H-H
	Reduced	C-W-B_F-O/B_R&A-H-H
	Organic	C-W-B_F-O/B_R&A-H-H

[1] F_T = tillage fallow, W = wheat, C = canola, L_{GM} = lentil green manure, F_C = chemical fallow, P = field pea,

B_M = malt barley, B_F = feed barley, S_C = sweet clover, S_{CGM} = sweet clover green manure, R = fall rye, F_X = flax, O = oats, B_R&A = bromegrass-alfalfa, and H = hay.

Energy Analysis

- All direct and indirect nonrenewable energy going into manufacture, formulation, packaging, transportation, maintenance and application of all inputs used in each production system were included.
- Energy output was taken as gross energy content (as measured by bomb calorimeter) of harvested grain less seed requirements.
- Energy use efficiency was calculated as: i) net energy produced (energy output minus energy input), and ii) ratio of energy output to energy input.

Results and Discussion

Overall Annual Energy Performance

- Total annual production of each cropping systems varied greatly among years (Figure 1), reflecting the effects of growing season weather conditions on crop yields.
- Annual total production was greatest in 1996, 1999, and 2000 when growing season precipitaion was above normal, and lowest in the drier years of 1997 and 1998.

Overall Annual Energy Performance

- The energy performance of the production systems, differed greatly among years (Table 1).
- Gross energy output, net energy production, and energy output/input ratio were highest in 1996 and lowest in 1998.
- Total energy inputs were highest in 2000, intermediate in 1997 and generally similar from 1996, 1998, and 1999.

Figure 1. Average Annual Total Production

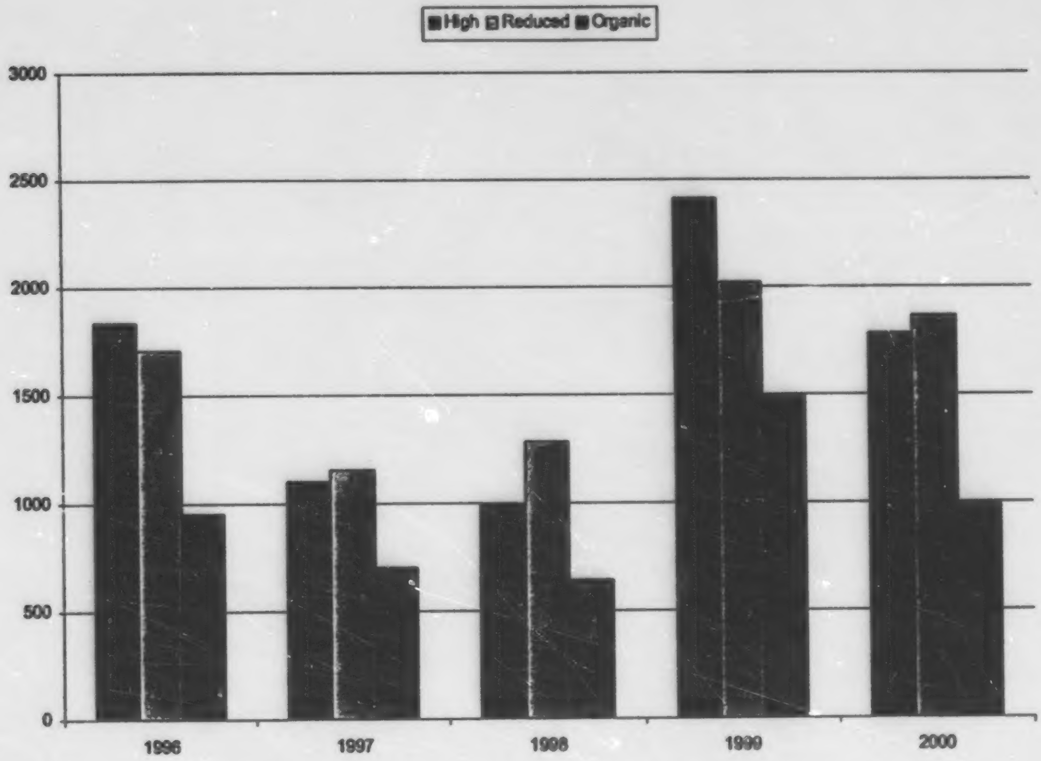


Table 1. Mean Annual Energy Performance (MJ ha^{-1})

Energy Parameter	1996	1997	1998	1999	2000
Gross Energy Output	35399	23396	17716	41689	30786
Total Energy Input	2739	2881	2627	2701	3903
Net Energy Production	32660	20515	15089	38988	26883
Energy Output/Input Ratio	12.9	8.1	6.7	15.4	7.9

Effect of Crop Diversity on Energy Performance

- Gross energy production ranged from 26621 MJ ha^{-1} for the DAP (with organic inputs) treatment to 59502 MJ ha^{-1} for DAG (with high inputs) (Table 2).
- Overall, gross energy output tended to be highest for DAG, intermediate for LOW (17% less) and lowest for DAP (33% less) treatments.
- Total energy input was highest for DAG, and lowest (and about equal) for DAP and LOW treatments(19% less).
- Net energy production displayed similar trends as for gross energy output.
- Energy output/input ratios were highest for DAG (with reduced inputs), and lowest for DAP (with high inputs).

Effect of Input Level on Energy Performance

- Gross energy production tended to be highest for High Input, intermediate for Reduced Input (15% less) and lowest for Organic (37%) treatments.
- Non-renewable energy requirements were highest for High Input and Reduced Input treatments and lowest for Organic Input (about 50% less) treatments.
- The energy Output/Input Ratio tended to be highest for Organic Input treatments, intermediate for High Input (24% less) and lowest for Reduced Input (41% less)

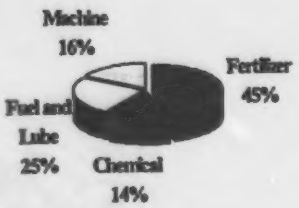
Table 2. Effect of Crop Diversity and Input Level on Energy Performance (MJ ha^{-1})

5-Year Average		Input Level			
Crop Diversity	Energy Parameter	High	Reduced	Organic	Mean
DAG	Gross Energy Output	4.1e+14	3.9e+14	1.9e+15	3.3e+14
	Total Energy Input				
	Net Energy Production				
	Energy Output/Input Ratio				
DAP	Gross Energy Output	3.2e+14	3.2e+14	2.1e+15	2.8e+15
	Total Energy Input				
	Net Energy Production				
	Energy Output/Input Ratio				
LOW	Gross Energy Output	3.3e+15	3.1e+14	2.0e+15	2.8e+15
	Total Energy Input				
	Net Energy Production				
	Energy Output/Input Ratio				
Mean Gross Energy Output		35071	34135	20186	29797
Mean Total Energy Input		3833	3562	1516	2970
Mean Net Energy Production		30875	30807	18806	26829
Mean Energy Output/Input Ratio		9.2	9.6	13.3	10

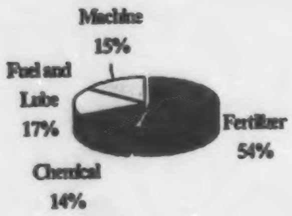
Effect of Energy Inputs by Crop Diversity

- As expected, the majority of the energy inputs used consisted of fertilizer and fuels.
- These two categories comprised over two thirds of the total energy inputs for all three diversity treatments.
- Fixed machinery energy was the third highest energy input, accounting for 18% to 22% of total energy inputs.
- DAG required the greatest total energy input, followed by DAP and then LOW.

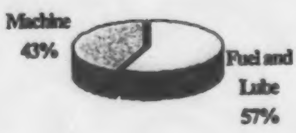
High



Reduced



Organic

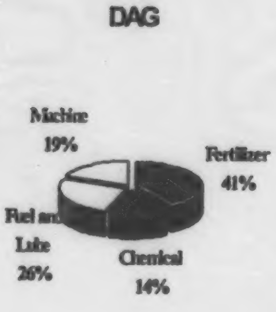


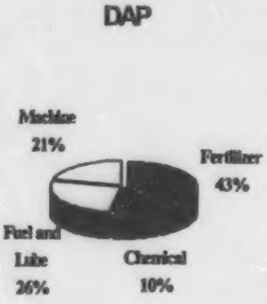
Effect of Energy Inputs by Input Level

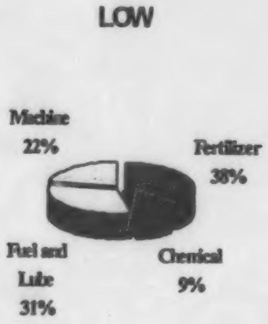
- Non-renewable energy requirements were highest and similar for the High Input and Reduced Input treatments and lowest for the Organic Input treatment.
- Savings in energy requirements for fertilizer and chemical in the Organic Input treatments were off-set somewhat by higher energy requirements for fuel.
- Use of Reduced Inputs provided some savings in energy for fuels and lubricants. However, fertilizer energy requirements were higher in proportion to total energy use than in the High Input treatments.

Conclusions

- Fertilizers (primarily N) and fuel were the major non-renewable energy inputs to all treatments, except organic treatments where fuel alone was the major energy input.
- Gross and net energy production tended to be highest for DAG, intermediate for LOW, and lowest for DAP treatments.
- Gross energy production tended to be highest for High Input and Reduced Input treatments and lowest for Organic Input treatments.
- The use of Organic Input levels showed potential to reduce total energy inputs by up to 50% compared to High Input and Reduced Input treatments.
- Non-renewable energy use efficiency was highest with Organic Input management.







Acknowledgment

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Alternative Cropping Systems
ACS Long-Term Agro-Ecosystem Research for the Canadian Prairie Ecozone
1994 - 2012
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Arthropod Diversity and Pest Dynamics As a Function of Production Input Levels and Cropping System Strategies

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Rationale

Sustainable management strategies, crop loss prevention and maintenance of soil health are central to our capacity to maintain the biological productivity of agricultural systems. Arthropods, including insects, spiders and mites, are integral to crop loss and to soil health because they include both beneficial and pest species. Cropping systems must incorporate the relationships between farm practices and the ecosystem to create an equilibrium where farm inputs enhance rather than replace natural processes.

Preserving Yield

Until recently, control of insect pests to reduce crop loss was not a particularly perplexing problem because of the wide acceptance of highly effective chemical insecticides. However, despite an estimated 2.5 million tonnes of insecticides used world-wide annually, pests destroy about 35% of all potential crops before harvest (Albert *et al.*, 1992). Approximately 12% of potential crop loss was attributed to arthropods (Pimentel, 1986). This strongly suggests that a significant number of other factors must be considered when developing strategies to preserve crop yield.

From an agronomic perspective, the major innovations in farming systems in the last decade have been crop diversification and the soil conservation practices of reduced- and zero-tillage. The extent to which these innovations have influenced, or may influence in the future, insect pest population dynamics is not fully documented. The Manitoba-North Dakota Zero Tillage Farmers Association published a manual for integrated management of insect pests in zero-tillage (Ellis, 1994), however, the manual does not document the impact that zero-tillage may have on the pest status of these insects.

From a pest management perspective, the major factors that influence pest status of insects are weather, habitat, food, and natural enemies. Cropping systems (crop residues, crop rotation and soil tillage) can play a major role in all of these factors. Much of the knowledge required to fully understand the complexities of relationships between beneficial arthropods and their habitat is still being developed. However, it is understood that cropping systems can play a significant role in the conservation of natural enemies through habitat management, crop structure, and diversity (Altieri, 1994).

Soil Health

The desire to maintain the capacity of the soil to sustain biological productivity has positively influenced the study of soil properties that contribute to the quality and health of our prairie soils. Acton and Padbury (1993) defined soil quality in terms of measurable soil properties that influence the capacity of the soil to perform crop production or environmental functions. Doran and Safley (1997) defined soil health as a living system that has the capacity to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal, and human health.

Communities of arthropods that live in the soil are influenced generally by the same factors that influence those living above ground. Species richness and the biological success of specific communities, are related positively to the diversity of niches, and soil micro-environments (van Straalen, 1997). As a result, the extent to which cropping diversity, rotational regimes, and soil preparation influence the diversity of micro-environments in the soil tremendously impact arthropod populations (Pankhurst *et al.*, 1997). Unfortunately, even less is known about most of the soil arthropods and the agro-ecological role they play than those living above ground (Freckman, 1994).

Soil micro-fauna are implicated in a number of soil processes such as decomposition of organic matter, nutrient mineralization, regulating micro flora (including plant pathogens), decomposition of agricultural chemicals and improving soil structure (Gupta and Yeates, 1997). Thus, protozoa, nematodes, and rotifers have potential as indicators of soil health because they tend to respond quickly to environmental changes in the soil.

Soil meso-fauna (mites, millipedes, collembolans are referred to as micro-arthropods by some authors) also are thought to be involved in processing organic matter and augmenting processes involved in soil structure (van Straalen, 1997). Because soil meso-fauna are still relatively sedentary they do reflect the conditions of the soil habitat more than more mobile macro-fauna. Meso-fauna are abundant in agricultural soils but much more needs to be learned about their contribution to soil processes (Crossley *et al.*, 1992). It has been reported that they are sensitive to agricultural chemical inputs and, as a result, they may also have potential as biological indicators of chemical impact on the ecosystem (Koehler, 1992).

Soil macro-fauna are sometimes involved in predation (spiders, ants) of pest species, however, others tend to play a role similar to meso-fauna in that their diet consists of primary and secondary consumers, they process organic matter and contribute to soil structure (van Straalen, 1997; Doube and Schmidt, 1997).

Methods

Pitfall Traps

The ground-dwelling predator fauna was sampled using pitfall traps constructed from 1L round plastic containers with an opening 11 cm in diameter. The traps were placed in the center of each sub plot as well as out in the grassed margins surrounding the field site. The traps were installed in the ground flush with the soil surface and fitted with a clear plastic funnel. When not in use the traps were covered with plastic lids to prevent the unnecessary capture of beetles and to keep debris and rain out of the traps. The pitfall captures were based on a 48 hour period. Due to a back log of samples collected, the pitfall trapping was conducted only in 1994, 1995, 1996 and 2000. The period of collection was during the growing season (June - August). Insects, spiders, phalangids and chilopods were identified to the family level; carabid beetles were identified to species level.

Soil Sampling

Soil core samples were taken on three occasions each year: pre-cultivation, mid-growing season and post-harvest. Each sample consisted of four soil cores (4 cm diameter, 15 cm depth) divided into upper and lower sub-samples.

The four samples were bulked and stored at +2 °C until processed. Because the samples were split into upper and lower portions only half of the 216 subplots were sampled (odd- numbered subplots). Four samples were also taken along the north edge of the field in a grassy fence-line. As well, an alfalfa-brome field (seeded about 30 years ago), an old grass field (seeded to grass about 60 years ago) and a native prairie field were also sampled. All of these fields are located at the Scott farm.

Biological activity in soils primarily takes place in topsoil, and is concentrated in the top 5-10 cm. To assess the soil microfauna, soil cores (4 cm in diameter at 15 cm depth) were collected from all test sites in 1996, at three different times during the year: pre-cultivation, mid-growing season and post-harvest. At the crop study site, four cores were taken from the odd-numbered sub-plots (n = 108). Each sample consisted of four soil cores (4 cm diameter, 15 cm depth) divided into upper and lower sub-samples. The four samples were bulked and stored at +2 °C until processed. At the uncultivated sites, four replicates of four soil cores were taken at random from within each area. **Tullgren** funnels and **Baermann** funnels were used to extract the organisms from the soil.

Tullgren Funnels

Tullgren funnels use heat and light to force arthropods living within the soil into a container of alcohol at the bottom of the funnel stem. The arthropods have been sorted and counted. The mites were sorted into four sub-orders; Actinendida, Acaridida, Gamasida, and Oribatida. Whenever possible the mites were sorted to family level. Mites were saved in alcohol and representative specimens were mounted on slides for further identification. The remaining micro-organisms such as nematodes and enchytraeids (Annelida) were also counted and sorted. Collembola and the larvae of Diptera and Coleoptera were sorted to the family level when possible.

Baerman Funnel

Baermann funnels also use light and the heat to force organisms living in the soil water from the soil. Thirty grams of the soil sample were placed in a glass funnel and covered with water. The intensity of light and heat is gradually increased over time to force the water-born organisms from the soil and into the bottom of the funnel stem. This water is drained into a vial and is examined under a stereo microscope. A black background is used so that the movement of the living organisms can be detected. Nematodes, Rotifers, Enchytraeids (Annelida) and protozoa were counted alive under a microscope with a dark background Protozoans and Tardigrades are counted and recorded.

Results and Discussion

Over the course of the study, more than 700, 000 arthropods have been collected, sorted and identified. The collection involves approximately 280 guilds (Species, Family, Order, etc). All specimens have been preserved in alcohol, catalogued and coded for entry into the ACS database.

Pitfall Trap Sampling

In order of decreasing abundance, the following arthropods have been enumerated from pitfall traps: Collembola > Arachnida > Coleoptera > Homoptera > Hymenoptera > Diptera > Hemiptera. The ground beetles (Carabidae; Coleoptera) represent one of the largest insect Families in North American with approximately 2500 species described (Arnett, 1968). They can be found in a wide range of temperate habitats including arable, boreal, riparian, and wetland environments. Carabid beetles are quite mobile on the soil surface, a characteristic that facilitates their capture using pitfall traps. The large number of species, their wide distribution, their relative ease of capture and their importance as biological control agents have made them a favoured group for agro-ecological research. The underlying assumption is that agricultural sustainability is enhanced in farming systems with a higher abundance

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and diversity of ground-dwelling predators. In this study, the predominant beetle Family captured in the pitfall traps was Carabidae (Coleoptera).

The total number of carabid beetle species captured in Year 6 (2000) varied between 15 and 24 species depending on crop diversity and input level (Table 1). The results show that the diversified annual grain rotation (DAG) had the greatest number of beetles species, followed by diversified annual and perennial rotation (DAP) and low rotation (LOW). Comparing the three input levels, organic production slightly favoured species richness.

Table 1. The total number of carabid species captured in 2000 in each of nine farming systems and in the grass margin ('E' = edge) surrounding the research site.

Input	Crop Diversity LOW	DAG	DAP	E	Mean
E				16	16.0
ORG	20	19	23		20.7
RED	15	21	18		18.0
HIGH	17	24	20		20.3
Mean	17.3	21.3	20.3	16.0	

The overall mean abundance (1995 - 2000) of carabid beetles captured per trap over a 48h trapping period varied from 2.8 - 6.8 beetles per trap. The results show that beetle abundance was higher in the organic input system, followed by high input and reduced input. In relation to cropping diversity, the diversified annual grain rotation (DAG) supported a higher population of carabid beetles than did the other two rotations. The grass margin surrounding the plot supported the least.

Table 2. The overall mean abundance of carabid beetles captured (1995 - 2000) in each of nine farming systems and in the grass margin ('E' = edge) surrounding the research site.

Soil Core Sampling

Input	Crop Diversity LOW	DAG	DAP	E	Mean
E				2.8	2.8
ORG	5.2	4.5	5.5		5.1
RED	3.1	5.7	2.9		3.9
HIGH	3.3	6.8	4.0		4.7
Mean	3.8	5.7	4.2	2.8	4.4

Tullgren Funnels

In order of decreasing abundance, the following arthropods were enumerated from the Tullgren funnels: Collembola > Acari > Coleoptera >Hymenoptera > Diptera. Mites (Acari or Acarina) are the most diverse and abundant of all arachnids, but because of their small size (usually less than a millimeter in length) we rarely see them. Mites are also among the oldest of all terrestrial arthropods, about 45,000 species of mites have been described (Lindquist 1984). Mites are truly ubiquitous. They have successfully colonized nearly every known terrestrial, marine, and fresh water habitat. Mites found in agricultural crops may be economic pests, useful biocontrol agents of those pests or living in the soil as contributors to soil health.

The Acari were sorted into four main sub-orders Astigmata, Mesostigmata, Prostigmata and Oribatida. The overall (all species, all years) mean abundance per sample of mites in the study ranged from 11.3 - 52.8 mites per sample (Table 3). Abundance of mites was significantly higher in all the uncultivated sites than in he cropped area. On average, all rotations within the reduced input system (RED) supported a greater number of soil mites than the other two input levels.

Table 3. The overall (all species, all years) mean abundance per sample of mites extracted from soil samples in the nine farming systems and the four uncultivated areas (E = grass margin, AB = alfalfa/brome, OP = old grass, NP = native grass).

Each of the different sub-orders of Acari responded somewhat different to the nine cropping systems and to the different levels of disturbance in the uncultivated areas (Tables 4-7). The sub-order Astigmata appears to be much more successful in the organic input system relative to reduced and high input systems. In general, the study showed that Astigmata abundance was lowest in the reduced input and the uncultivated grass sites (Table 4).

	Input			GRASSES				
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	19.0	29.1	11.3					19.8
DAG	17.0	28.1	17.3					20.8
DAP	16.4	23.7	13.4					17.8
E				44.7				
AB					45.3			
OP						30.5		
NP							52.8	
Mean	17.5	27.0	14.0					

Table 4. The overall mean abundance per sample of Astigmata mites extracted from soil samples in the nine farming systems and the four uncultivated areas (E = grass margin, AB = alfalfa/brome, OP = old grass, NP = native grass).

The sub-order Mesostigmata appears to be more successful in the reduced input system relative to organic and high input systems (Table 5). Cropping diversity had little effect on Mesostigmata abundance. All of the grass sites supported a larger population of Mesostigmata than did the cropped area.

	INPUT			GRASS				
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	9.7	3.7	6.9					6.8
DAG	13.5	5.3	10.6					9.8
DAP	13.3	4.5	7.8					8.5
E				5.2				
AB					6.7			
OP						1.8		
NP							2.1	
Mean	12.2	4.5	8.4					

and diversity of ground-dwelling predators. In this study, the predominant beetle Family captured in the pitfall traps was Carabidae (Coleoptera).

The total number of carabid beetle species captured in Year 6 (2000) varied between 15 and 24 species depending on crop diversity and input level (Table 1). The results show that the diversified annual grain rotation (DAG) had the greatest number of beetles species, followed by diversified annual and perennial rotation (DAP) and low rotation (LOW). Comparing the three input levels, organic production slightly favoured species richness.

Table 1. The total number of carabid species captured in 2000 in each of nine farming systems and in the grass margin ('E' = edge) surrounding the research site.

The overall mean abundance (1995 - 2000) of carabid beetles captured per trap over a 48h trapping period varied from 2.8 - 6.8 beetles per trap. The results show that beetle abundance was higher in the organic input system, followed by high input and reduced input. In relation to cropping diversity, the diversified annual grain rotation (DAG) supported a higher population of carabid beetles than did the other two rotations. The grass margin surrounding the plot supported the least.

	Crop Diversity				
Input	LOW	DAG	DAP	E	Mean
E				16	16.0
ORG	20	19	23		20.7
RED	15	21	18		18.0
HIGH	17	24	20		20.3
Mean	17.3	21.3	20.3	16.0	

Table 2. The overall mean abundance of carabid beetles captured (1995 - 2000) in each of nine farming systems and in the grass margin ('E' = edge) surrounding the research site.

Soil Core Sampling

	Crop Diversity				
Input	LOW	DAG	DAP	E	Mean
E				2.8	2.8
ORG	5.2	4.5	5.5		5.1
RED	3.1	5.7	2.9		3.9
HIGH	3.3	6.8	4.0		4.7
Mean	3.8	5.7	4.2	2.8	4.4

Tullgren Funnels

In order of decreasing abundance, the following arthropods were enumerated from the Tullgren funnels: Collembola > Acari > Coleoptera >Hymenoptera > Diptera. Mites (Acari or Acarina) are the most diverse and abundant of all arachnids, but because of their small size (usually less than a millimeter in length) we rarely see them. Mites are also among the oldest of all terrestrial arthropods, about 45,000 species of mites have been described (Lindquist 1984). Mites are truly ubiquitous. They have successfully colonized nearly every known terrestrial, marine, and fresh water habitat. Mites found in agricultural crops may be economic pests, useful biocontrol agents of those pests or living in the soil as contributors to soil health.

The Acari were sorted into four main sub-orders Astigmata, Mesostigmata, Prostigmata and Oribatida. The overall (all species, all years) mean abundance per sample of mites in the study ranged from 11.3 - 52.8 mites per sample (Table 3). Abundance of mites was significantly higher in all the uncultivated sites than in he cropped area. On average, all rotations within the reduced input system (RED) supported a greater number of soil mites than the other two input levels.

Table 3. The overall (all species, all years) mean abundance per sample of mites extracted from soil samples in the nine farming systems and the four uncultivated areas (E = grass margin, AB = alfalfa/brome, OP = old grass, NP = native grass).

	Input		GRASSES					
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	19.0	29.1	11.3					19.8
DAG	17.0	28.1	17.3					20.8
DAP	16.4	23.7	13.4					17.8
E				44.7				
AB					45.3			
OP						30.5		
NP							52.8	
Mean	17.5	27.0	14.0					

Each of the different sub-orders of Acari responded somewhat different to the nine cropping systems and to the different levels of disturbance in the uncultivated areas (Tables 4-7). The sub-order Astigmata appears to be much more successful in the organic input system relative to reduced and high input systems. In general, the study showed that Astigmata abundance was lowest in the reduced input and the uncultivated grass sites (Table 4).

Table 4. The overall mean abundance per sample of Astigmata mites extracted from soil samples in the nine farming systems and the four uncultivated areas (E = grass margin, AB = alfalfa/brome, OP = old grass, NP = native grass).

	INPUT			GRASS				
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	9.7	3.7	6.9					6.8
DAG	13.5	5.3	10.6					9.8
DAP	13.3	4.5	7.8					8.5
E				5.2				
AB					6.7			
OP						1.8		
NP							2.1	
Mean	12.2	4.5	8.4					

The sub-order Mesostigmata appears to be more successful in the reduced input system relative to organic and high input systems (Table 5). Cropping diversity had little effect on Mesostigmata abundance. All of the grass sites supported a larger population of Mesostigmata than did the cropped area.

Table 5. The overall mean abundance per sample of Mesostigmata mites extracted from soil samples in the nine farming systems and the four uncultivated areas (E = grass margin, AB = alfalfa/brome, OP = old grass, NP = native grass).

The sub-order Prostigmata appears to be much more successful in the reduced input system relative to organic and high input systems (Table 6). In general, the study showed that Prostigmata abundance was lowest in the high input. In relation to cropping diversity, the diversified annual grains rotation (DAG) had a mean abundance of Prostigmata greater than the other two rotations. All of the grass sites supported a significantly larger population of Prostigmata than did the cropped area.

	INPUT		GRASSES					
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	6.9	11.8	4.2					7.6
DAG	6.2	11.2	6.8					8.1
DAP	6.1	11.0	5.1					7.4
E				24.2				
AB					13.2			
OP						13.3		
NP							17.0	
Mean	6.4	11.3	5.4					

Table 6. The overall mean abundance per sample of Prostigmata mites extracted from soil samples in the nine farming systems and the four uncultivated areas (E = grass margin, AB = alfalfa/brome, OP = old grass, NP = native grass).

The sub-order Oribatida appears to be much more successful (2X) in the reduced input system relative to organic and high input systems (Table 7). In relation to cropping diversity, the low diversity rotation had a mean abundance of Oribatida greater than the other two rotations. The native grass site supported the greatest population of Oribatid mites.

	INPUT		GRASSES					
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	36.4	58.8	18.3					37.9
DAG	31.7	62.4	31.8					41.9
DAP	31.9	46.0	23.4					33.7
E				114.4				
AB					119.8			
OP						68.3		
NP							113.9	
Mean	33.3	55.7	24.5					

Table 7. The overall mean abundance per sample of Oribatid mites extracted from soil samples in the nine farming systems and the four uncultivated areas (E = grass margin, AB = alfalfa/brome, OP = old grass, NP = native grass).

	INPUT			GRASSES				
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	23.1	42.1	15.8					27.0
DAG	16.4	33.5	20.1					23.3
DAP	14.3	33.3	17.2					21.6
E				35.2				
AB					41.6			
OP						41.3		
NP							78.2	
Mean	17.9	36.3	17.7					

Oribatida

In this study, emphasis has been placed on the Oribatid mites because of the implications for soil health. Oribatid mites, also known as soil mites, range in size from 0.2 - 1mm and occur primarily in the top layer of the soil and in plant debris. They are responsible for breaking up organic matter and for recycling minerals in the soil. Hence they can play an important role in soil fertility. Population abundance, but more importantly, species richness, can serve as bio-indicators of soil health. Because they are easy to collect and easy to store, they are very useful in this respect.

In addition, to the impact of different farming systems on Oribatid mites (Table 7), their abundance was influenced by the different crops being grown in rotation (Figure 1.) Broad-leaf crops (flax, peas and canola) supported significantly fewer Oribatid mites than did the grass crops, especially fall rye. In general, the abundance of Oribatid mites was the greater in the un-cultivated areas than in the cropped areas, except for fall rye.

Figure 1. Overall mean abundance per soil sample of Oribatid mites in relation to crop type.

Baermann Funnels

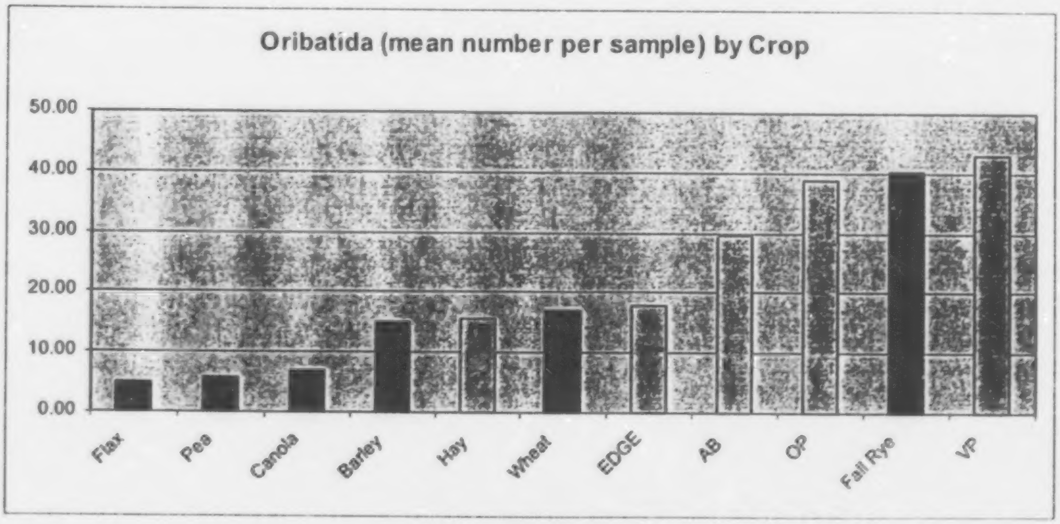

Table 5. The overall mean abundance per sample of Mesostigmata mites extracted from soil samples in the nine farming systems and the four uncultivated areas (E = grass margin, AB = alfalfa/brome, OP = old grass, NP = native grass).

The sub-order Prostigmata appears to be much more successful in the reduced input system relative to organic and high input systems (Table 6). In general, the study showed that Prostigmata abundance was lowest in the high input. In relation to cropping diversity, the diversified annual grains rotation (DAG) had a mean abundance of Prostigmata greater than the other two rotations. All of the grass sites supported a significantly larger population of Prostigmata than did the cropped area.

	INPUT		GRASSES					
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	6.8	11.8	4.2					7.6
DAG	6.2	11.2	6.8					8.1
DAP	6.1	11.0	5.1					7.4
E				24.2				
AB					13.2			
OP						13.3		
NP							17.0	
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The sub-order Oribatida appears to be much more successful (2X) in the reduced input system relative to organic and high input systems (Table 7). In relation to cropping diversity, the low diversity rotation had a mean abundance of Oribatida greater than the other two rotations. The native grass site supported the greatest population of Oribatid mites.

	INPUT		GRASSES					
Diversity	ORG	RED	HIGH	E	AB	OP	NP	Mean
LOW	36.4	58.8	18.3					37.9
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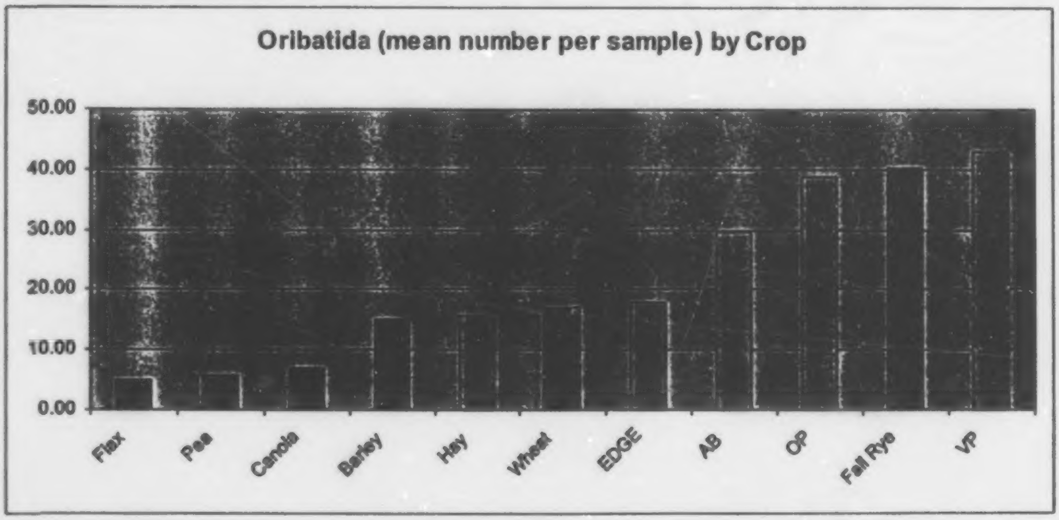

In order of decreasing abundance, the following microfauna were enumerated from the Baermann funnels: Nematodes > Rotifers > Protozoans > Enchytraeids > Tartigrades. Nematodes are commonly found in most habitats, but are often overlooked because they are microscopic in size. At recent count, more than 15,000 species of nematodes had been described. Soil is a superb habitat for nematodes; it is estimated that 100 cc of soil contains thousands of individuals. Unfortunately, there is a much less known about soil nematodes than about those present on plants. In general those living in the soil do not parasitize plants, but are a major contributor to decomposition of organic matter. Because most nematodes inhabit the thin film of moisture around soil particles, the micro-environment surrounding plant roots and root hairs is a particularly suitable habitat. Therefore, it would be anticipated that different cropping systems would influence nematode populations in different ways.

Nematodes

In this study, nematodes were not identified beyond Phylum. Results indicate mean nematode populations were greater in the reduced input (RED) and the diversified annual grains rotation (DAG) than in the other cropping systems Table 8). In all cases, nematode populations were significantly lower in the cropped area than in the uncultivated grass areas. In the grass areas, nematode abundance appears to be negatively related to soil disturbance (ie. age of grass stand). The grass margins (E = edge) around the study site has not been cultivated for approximately 15 years, the alfalfa/brome (AB) is about 30 years old, and the older grass area (OP) was cultivated and seeded back to grass about 60 years ago. The native prairie grass area (NP) had significantly higher population density than any other site.

Table 8. The overall mean abundance of nematodes per soil sample in nine cropping systems and four grass stands of differing age.

The primary features of the other Phyla were: the High input system (HIGH) had significantly fewer Enchytraeids and protozoans than the Reduced input system (RED) and the organic input system (ORG); there was greater abundance of Protozoa in the grass ecosystems than in the crop land; there was a greater abundance of Rotifera in the Reduced input level plots than in the other input level systems; and no Tartigrada have yet been recorded in the low cropping diversity plots.

DIVERSITY			GRASSES						
INPUT	LOW	DAG	DAP	E	AB	OP	NP	Mean	
ORG	332.0	431.2	322.6					361.9	
RED	393.5	375.8	398.9					389.4	
HIGH	222.6	287.7	276.9					262.4	
E				540.1					
AB					560.0				

In summary, there appears to be a sound basis for investigating arthropods and other soil micro-fauna as indicators of soil health. Pankhurst *et al* (1997) reported that both nematodes and protozoa abundance and diversity had a medium and high ranking, respectively, as indicators of soil health. In their opinion, mites and Collembola abundance and diversity both had a medium ranking as suitable indicators of soil health.

Much of the knowledge required to fully understand the relationships between beneficial arthropods and the soil is still being developed for the Northern Great Plains. However, it is understood that cropping systems can play a positive role in conservation of natural enemies through habitat management, crop structure, and diversity.

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In summary, there appears to be a sound basis for investigating arthropods and other soil micro-fauna as indicators of soil health. Pankhurst *et al* (1997) reported that both nematodes and protozoa abundance and diversity had a medium and high ranking, respectively, as indicators of soil health. In their opinion, mites and Collembola abundance and diversity both had a medium ranking as suitable indicators of soil health.

Much of the knowledge required to fully understand the relationships between beneficial arthropods and the soil is still being developed for the Northern Great Plains. However, it is understood that cropping systems can play a positive role in conservation of natural enemies through habitat management, crop structure, and diversity.

Because, interactions among the biological, physical and chemical components of agricultural systems is inherently complex, the design, data collection and evaluation of the findings depends on the collaborative efforts of multi-disciplinary team of crop, pest, economic and soil scientists. In addition, such evaluations often involve a long-term commitment to monitoring specific components within the agricultural system to determine rate and direction of change over time. Arthropods are well-suited to characterizing the ecosystems that they inhabit. Ecosystem-based, baselines of arthropod diversity and abundance are an integral component in evaluating farming systems and will contribute to our understanding of the impact of cropping systems on sustainability issues.

Alternative Cropping Systems
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Diversity and Activity of Arbuscular Mycorrhizal Fungi in Conventional, Reduced and Organic Input Systems in Saskatchewan, Canada

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Rationale

The AMF constitute the most common of all soil fungi that form mutualistic, symbiotic associations with the roots of more than 80% of vascular plants (Hayman, 1981). The types of benefits accrued to plants from this association are improved plant growth and yield, increased nutrient uptake (e.g., phosphorus, zinc, copper, and water), and biological control of soil-borne plant diseases (Jakobsen et al. 1992; Boyetchko and Tewari, 1996). Many economically important crops are known to derive benefits from mycorrhizal fungi.

Agricultural practices (such as crop rotation, fertilization, and pesticide use) have a tremendous impact on AMF populations (Johnson et al. 1992; Hendrix et al. 1995; Bever et al. 1996). However, relatively little is known about the occurrence and importance of these fungi in intensive agriculture, although several investigations have been initiated (Baltruschat and Dehne, 1988; Stöppler et al., 1990; Vivekanandan and Fixen, 1991; McGonigle and Miller, 1993; Franke-Snyder et al. 2001). Tillage and soil disturbance as well as high fertilizer levels appear to reduce mycorrhizal colonization (McGonigle and Miller, 1993). The level and effectiveness of mycorrhizal root colonization is known to decrease with high inputs of phosphorus and nitrogen fertilizers (Hayman 1975; Douds and Schenck, 1990). In fact, it was suggested that different plant species grown in low-input systems (ecological agriculture) had greater mycorrhizal root colonization than those plants grown under conventional cropping systems (Steffan, 1983). Significant reductions in level of mycorrhizal root colonization in crops after fallow has also been reported (Kucey and Paul, 1983; Harinikumar and Bagyaraj, 1988).

Because of the need for a living host (i.e. plant) to complete their life-cycle, AMF cannot be introduced into agricultural situations through conventional inoculation techniques (such as what is commonly done for rhizobial inoculants). We must therefore rely on naturally-occurring AMF populations in field soil and manipulate them through crop management to realize their potential benefits. It may be possible to manipulate and increase natural mycorrhizal populations and thus enhance the benefits of mycorrhizal symbioses through crop rotations and other farm management strategies. It may also be possible to reduce inputs, such as phosphorus fertilizers, and enhance mycorrhizal root colonization to utilize fertilizers more efficiently (Xavier and Germida, 1997). Moreover, improving crop growth and development with AMF may make crops more competitive against weed populations and therefore have potential as a means for enhancing crop competitiveness.

Methods

Site Characterization

Taxonomic Identification

AMF are obligate symbionts which require a living host to complete their life cycle. Therefore, multiplication of AMF spores must be conducted in 'pot cultures' which consist of soil (field soil) either alone or mixed with autoclaved greenhouse soil and planted with a host (i.e. legumes, such as alfalfa, are often used for this purpose). After a minimum of 3 to 4 months (and up to 1 year) in the greenhouse, spores of AMF can be extracted from the soil by a wet-sieving and decanting method, and individual spores retrieved and observed by light microscopy and scanning electron microscopy. Identification to the genus level is determined very easily by observation of a hyphal attachment, but detailed observations of the spore wall morphology are required to determine the species of the fungus.

Abundance and Spatial Distribution of Mycorrhizal Inoculum in the Field

A total of 520 soil samples were collected from the test site on June 8-10, 1994. Soil cores were 1 5/8" in diameter and taken at a 6" depth. The soil cores were taken from 216 plots, corresponding to the plots for each treatment; samples were taken from the north and south end of each 216 plot, totalling 432 samples. In addition, 88 soil cores were taken from the perimeter of the test site (i.e. guard rows: 10 m from the west, east and south side of each plot and 5 m from the north side of each plot).

The method used to measure the amount of mycorrhizal inoculum in the field is a 'Most-Probable Number' (MPN) method (Porter, 1979). Each soil sample was serially diluted ten-fold, in triplicate, from 100, 10-1, and 10-2 with autoclaved sand as the diluent. A dilution of 5 x 10-1 was also included in the dilution series. The diluted soil was placed in cone-tainers®, and seeded with alfalfa as a host plant and grown for 6 weeks. At harvest, the roots were washed, cleared, and stained using the method of Phillips and Hayman (1970), examined microscopically with stereoscopic and compound light microscopes, and presence or absence of infection were determined. The MPN of AMF propagules was calculated using MPN tables which provides an accurate measure of the level of viable (as opposed to total viable and dead) propagules of AMF.

Annual AMF root colonization

In 1995,1996 and 1997, roots of all crops were sampled between July 30 and August 2. For each treatment where the crops were present, root samples of at least 20 plants were randomly taken and pooled into one large sample for each treatment. Not all crops (e.g. lentils and peas) were collected because they were plowed under prior to our sampling date. Roots were washed with tap water and stored in preservative (95 ml 50% EtOH and 5 ml acetic acid).

Prior to root colonization assessment, roots were cleared in 5% KOH at 90 C for 1 hour, and stained with trypan blue lactic acid stain (Phillips and Hayman, 1970). Excess stain was removed by soaking roots in de-staining solution (equal amounts of water and 80% lactic acid).

The level of root colonization by AMF was microscopically assessed using a grid-line intersect method (Giovannetti and Mosse, 1980). Roots were spread onto a Petri plate underlaid with a 1 cm x 1 cm grid. Only root segments which intersected the vertical lines of the grid were counted and assessed microscopically as either non-infected or infected with mycorrhizal hyphae. When more detailed observations were necessary, the roots were examined under a compound light microscope. All data were recorded as percent root colonization. Statistical analyses were conducted on transformed data (arcsine transformation) using the General Linear Models procedure.

Results and Discussion

Site Characterization

Taxonomic Identification

Pot cultures were established and alfalfa plants grown for over 1 year. The taxonomic identification has been initiated. There appears to be more than one species in the field; therefore, it will take additional time to sort out the various spore morphologies and thus, final identification. Light microscopy has been initiated to determine the taxonomic placement of the AMF species. Preliminary evaluation has revealed that some of the fungi belong to the genus Glomus. A great deal of hyperparasitism (i.e. parasitism of spore walls by soil fungi, bacteria, and amoebae) was observed and made identification to species level more difficult. Additional pot cultures were established and multiplication of the AMF has been completed. Further microscopy, including light and scanning electron microscopy will be used to elucidate the identity of these fungi to species level. Some species of AMF fungi have been identified by other researchers in Saskatchewan (Kucey and Paul, 1983; Talukdar and Germida, 1993; Kennedy et al. 1999). The majority of these species belonged to the genus Glomus.

Abundance and Spatial Distribution of Mycorrhizal Inoculum in Field

A total of 12 alfalfa roots per soil core (6240 root samples in total) was evaluated for AMF colonization using the MPN method in order to provide an estimation of the spatial distribution of viable AMF propagules at the field site. Inclusion of the soil dilution 5 x 10-1 provided more sensitivity to the data, as opposed to the ten-fold serial dilutions (100, 10-1, and 10-2) alone.

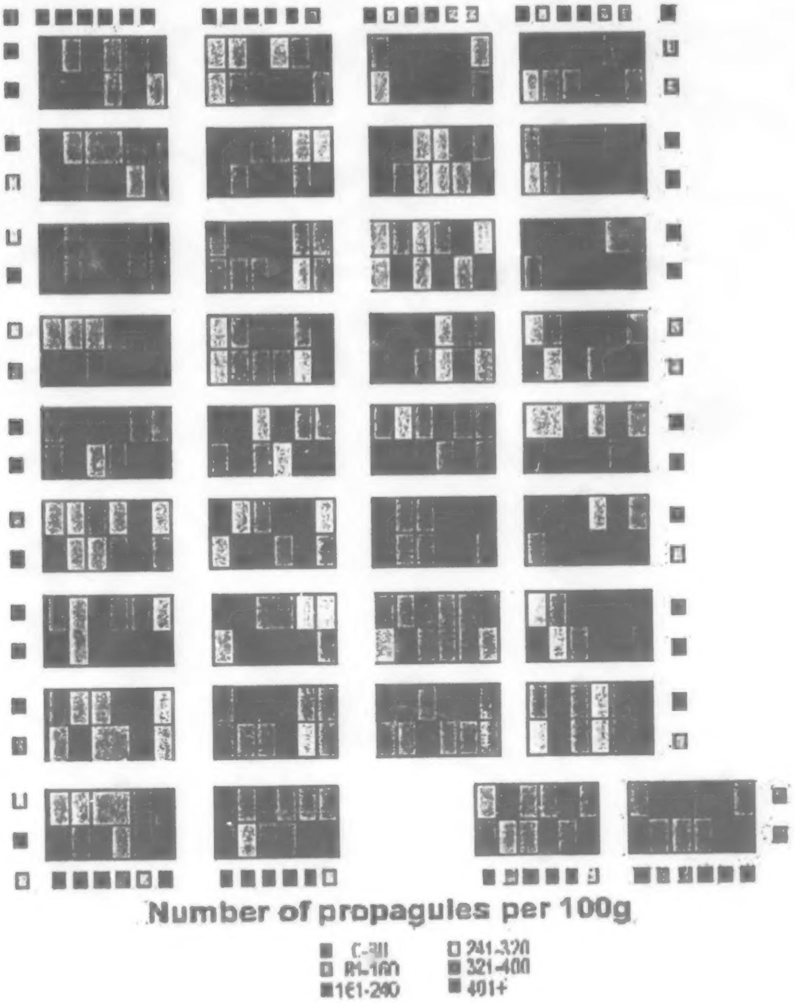
The results from the MPN study are summarized in Table 1 and Figure 1. Within the field plot (main plot from which the 432 soil samples were collected), the propagule densities ranged from 0 to 500 spores per 100 g soil, with the majority of the soil samples containing 110 to 210 spores per 100 g soil (Table 1). One sample contained in excess of 1900 spores per 100 g soil. From the soil cores taken from the perimeter of the plot (88 soil samples), spore densities ranged from 1 to 490 spores per 100 g soil.

Table 1. Number of viable AMF propagules recovered from 520 soil cores based on Most Probable Number method.

# of AMF spores per 100 g soil	Field plot samples Number of soil cores (Frequency)	Perimeter samples (Guard rows) Number of soil cores (Frequency)
0	6	0
1-100	44	16
101-150	141	9
151-200	56	18
201-250	71	9
251-300	88	12
301-500	25	24
>500	1	0
Total	432	88

Figure 1 provides a spatial distribution of the AMF populations, indicating which areas in the field contain lower and higher densities of AMF spores. Within the main field plot, some notable areas where spore densities are relatively higher are in the southwest (plots 1-12) and northwest (plots 44-54) corners of the field, as well as plots 151-155 and plots 182 and 187-194 in the east and northeast areas of the field. From the soil samples collected from the perimeter of the field, those on the west side of the plot ranged from 80 to 240 spores per 100 g soil (average), while the east side of the plot contained some areas with high spore densities (greater than 240 spores per 100 g soil).

Figure 1. Spatial distribution of mycorrhizal spore populations: 1994

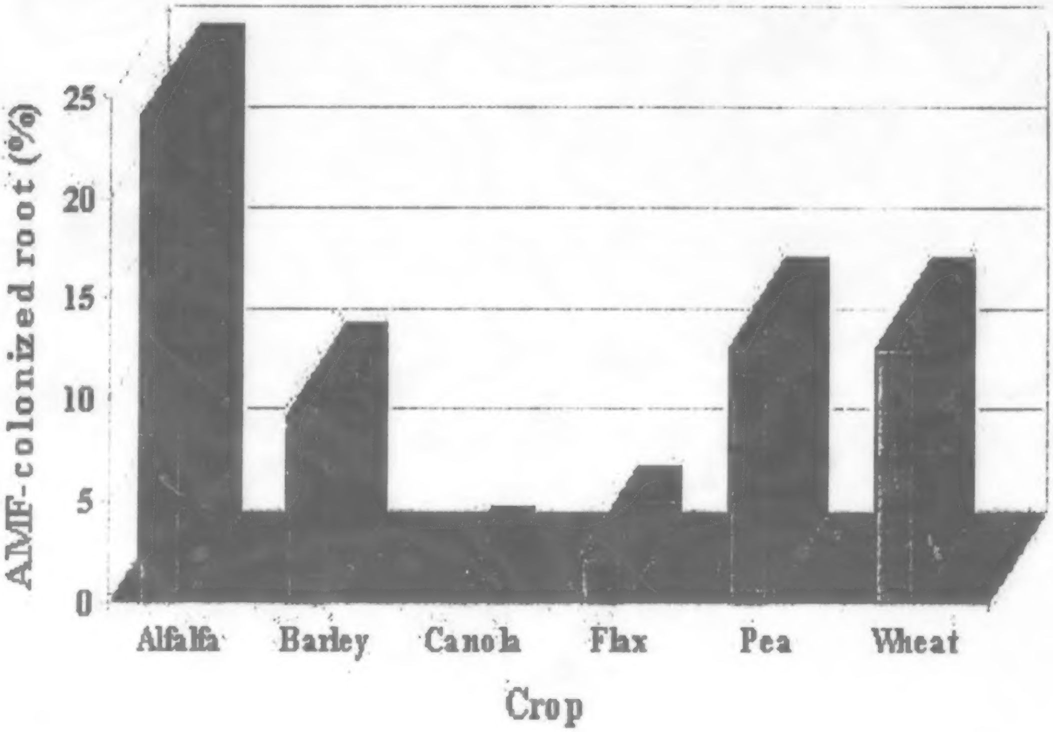


Annual AMF Root Colonization

1995

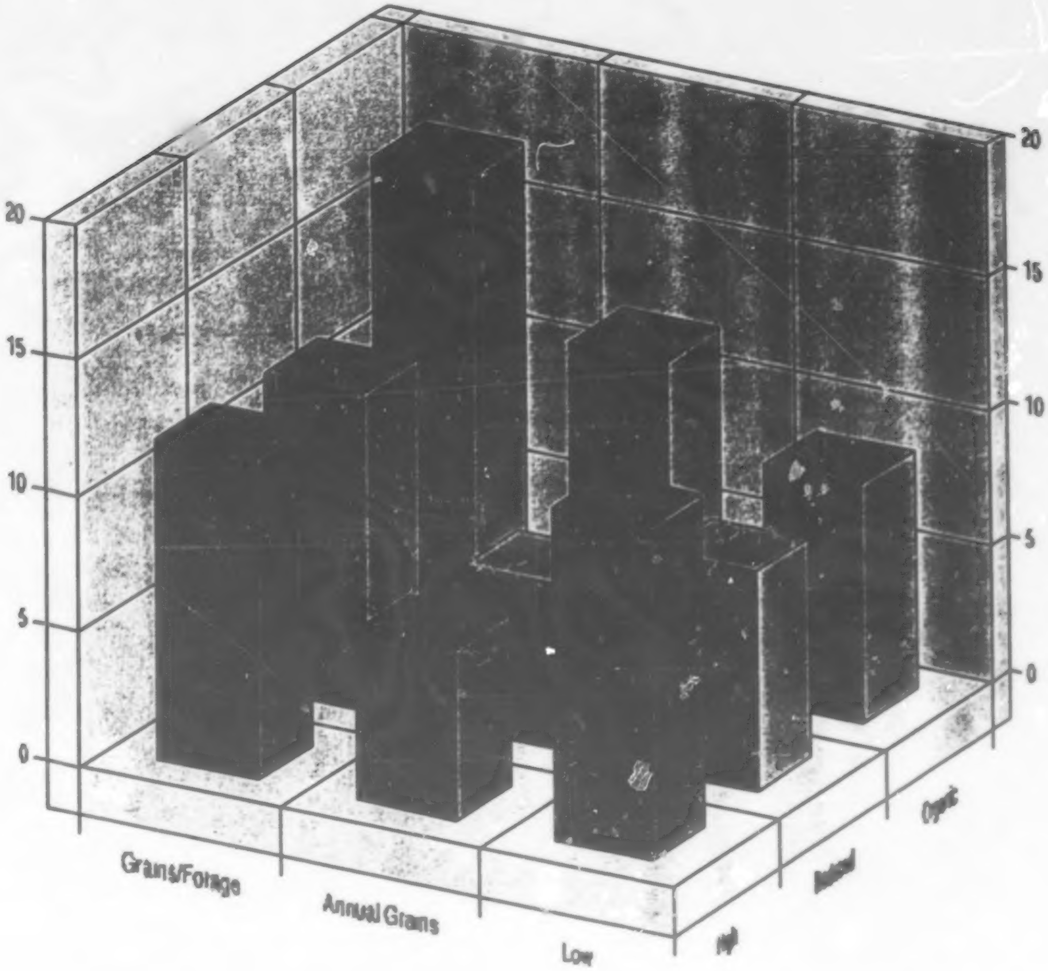
Of all the crops evaluated, alfalfa showed the highest level of root colonization (24%), followed by peas (12.5%), wheat (12.5%) and barley (9.3%) (Figure 2). Minimal root colonization was detected in canola (0.3%) and flax (2.3%).

Figure 2. Susceptibility of crops to AMF (1995)



In general, the highest level of mycorrhizal root colonization occurred with crops grown under the organic input system (Figure 3), while root colonization was similar in the high and reduced input systems. Crops grown under the grain/forage rotation yielded significantly higher root colonization than crops grown under the low and annual grains rotation system (Figure 3). In the organic and reduced input systems, crops grown in the grains/forage rotation had relatively higher levels of mycorrhizal root colonization (17.3% and 11.8%, respectively) compared to the annual grains and the low diversity rotation systems. However, in the high input system, crops grown in the grains/forage and low diversity rotations were similar (11.9% and 12.3%, respectively), compared to those grown in the annual grains system (6.3%).

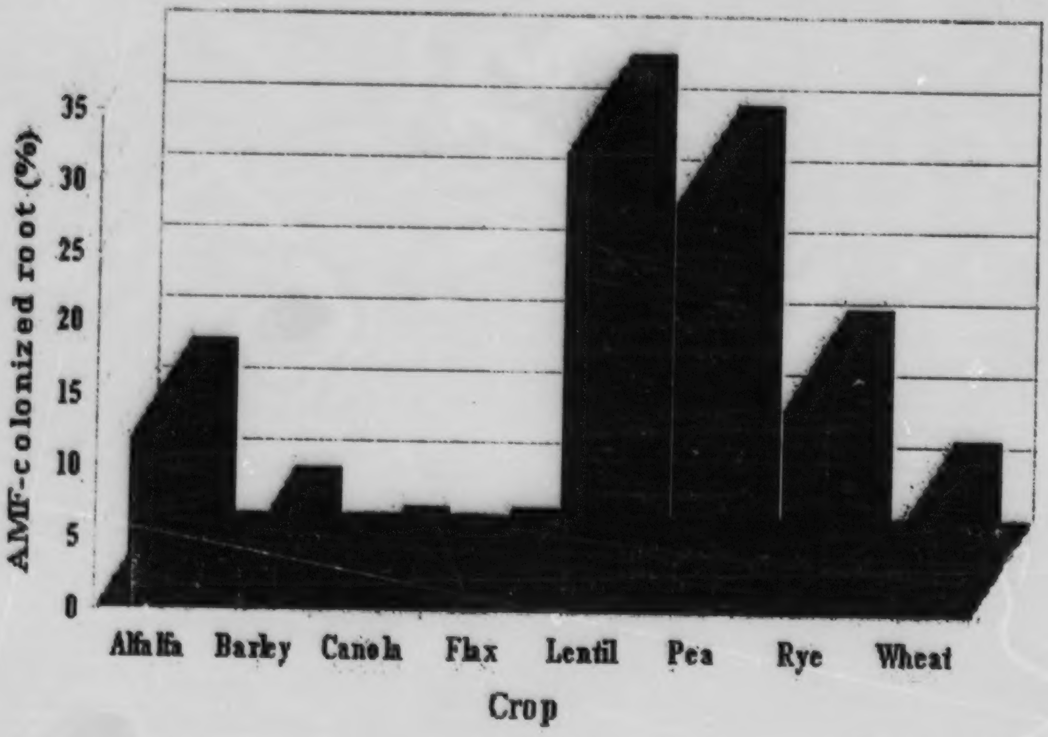
Figure 3. Influence of input levels and crop diversity on AMF colonization (1995)



1996

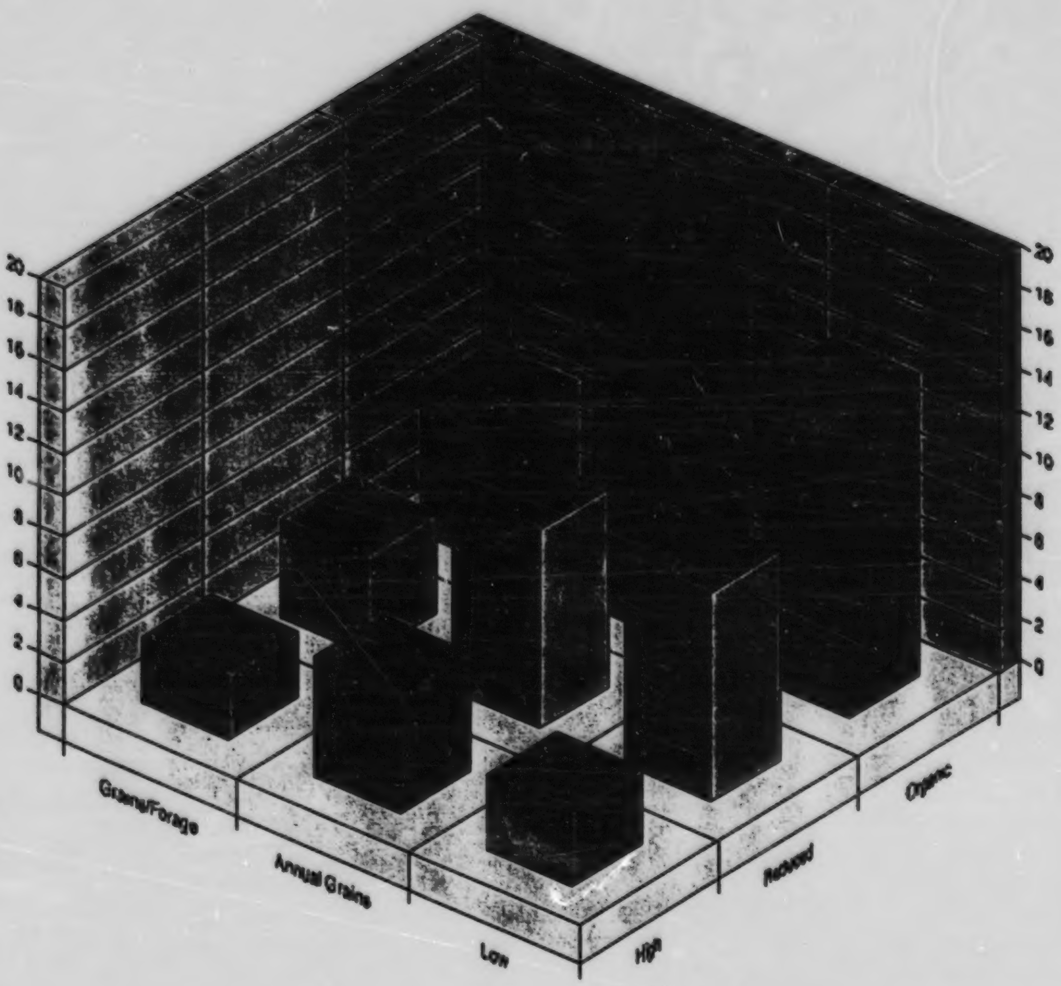
Of all the crops evaluated, lentils showed the highest level of root colonization (32.3%), followed by peas (28.7%), alfalfa (11.9%) wheat (5.3%) and barley (9.3%) (Figure 4). Minimal root colonization was detected in canola (0.0%) and flax (0.5%).

Figure 4. Susceptibility of crops to AMF (1996)



In general, the highest level of mycorrhizal root colonization occurred with crops grown under the organic input system (Figure 5) followed by the reduced input and high input systems. Crops grown under the annual grains rotation yielded significantly higher root colonization, followed by those grown under the low diversity and grain/forage rotation systems (Figure 5). More specifically, crops grown in the annual grains rotation of the organic input system had a mycorrhizal root colonization level of 19.7%, compared to 14.5% in the low diversity and 7.0% in the grain/forage rotation. For the reduced input system, mycorrhizal root colonization was similar in the annual grains rotation (9.5%) and the low diversity rotation (10.0%), while crops grown in the grains/forage rotation had 4.8% root colonization. In the high input system, the mycorrhizal root colonization was 5.6% in the annual grains, 3.7% in the low diversity, and 3.2% in the grains/forage rotations.

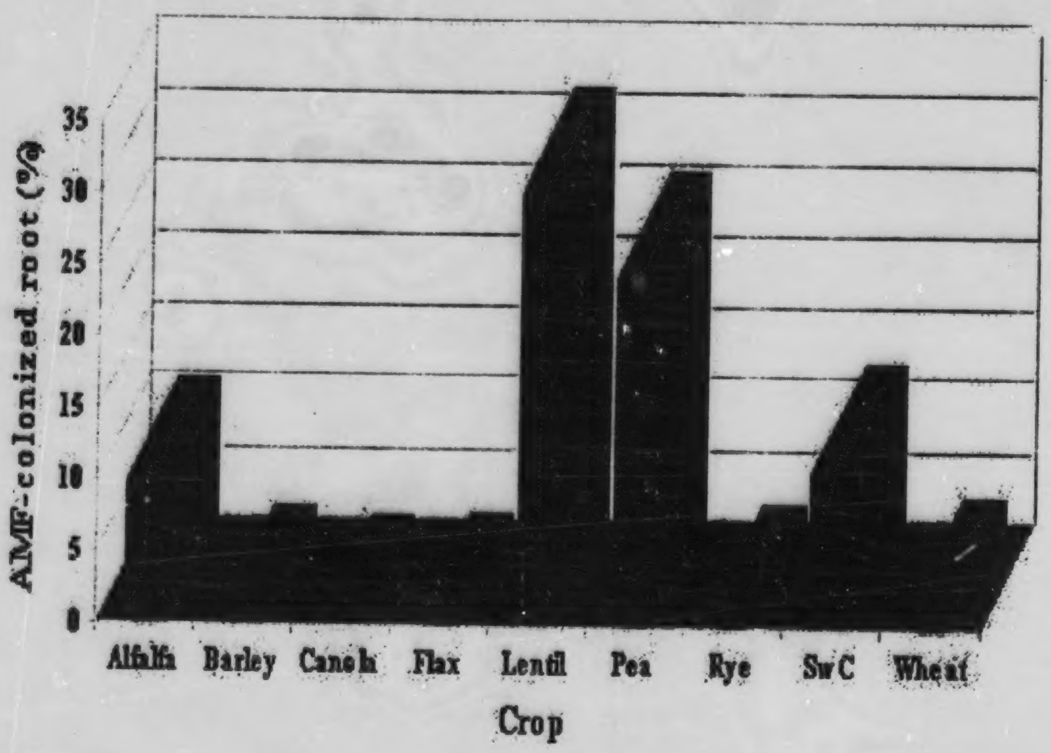
Figure 5. Influence of input levels and crop diversity on AMF colonization (1996)



1997

In general, mycorrhizal root colonization was lower in all crops in 1997, compared to 1995 and 1996. The reason may be attributed to the dry environmental conditions that occurred during crop development in the mid-summer. Of all the crops evaluated, lentils showed the highest level of root colonization (30.3%), followed by peas (24.4%), sweet clover (11.0%), and alfalfa (9.8%). The mycorrhizal root colonization in cereals was particularly low in 1997; root infection in wheat, barley and rye was 1.7%, 0.8%, and 1.2%, respectively (Figure 6). Minimal root colonization was detected in canola (0.3%) and flax (0.5%).

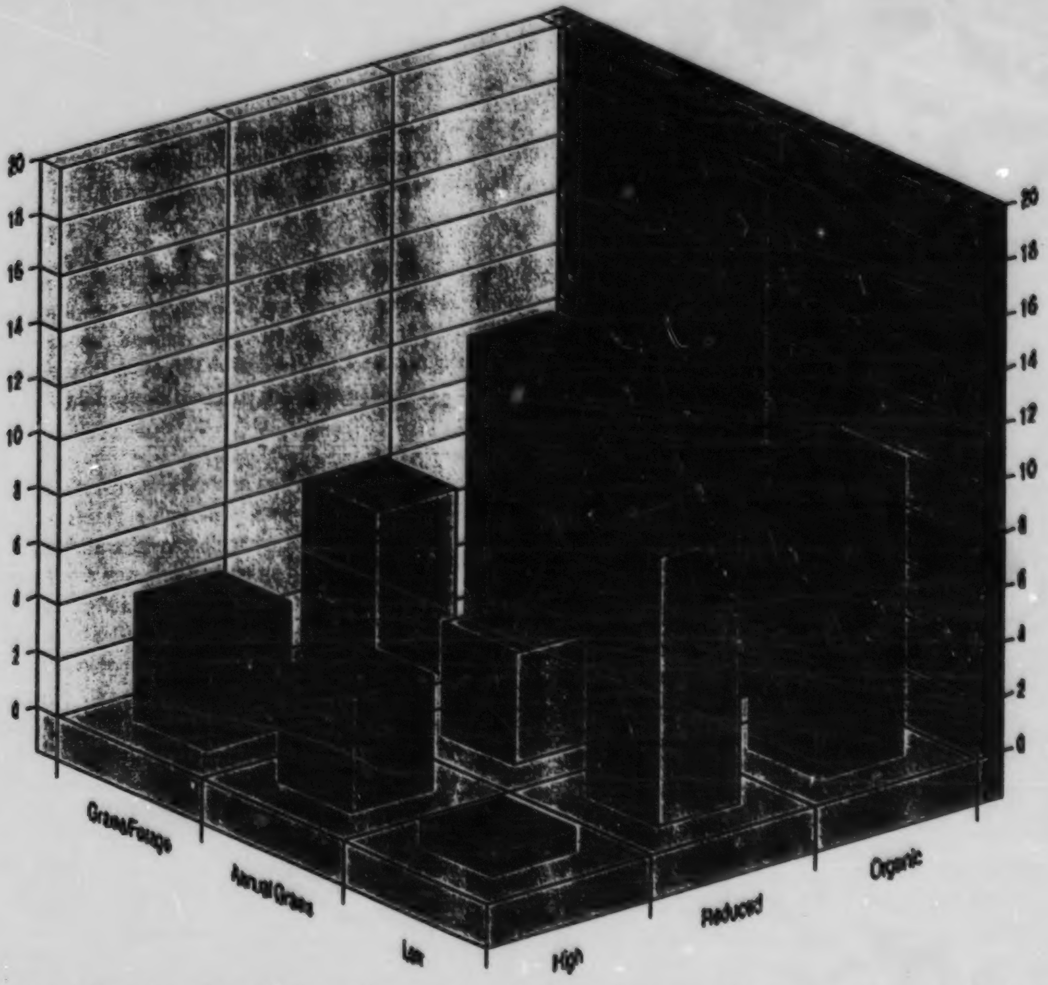
Figure 6. Susceptibility of crops to AMF (1997)



The highest level of mycorrhizal root colonization occurred with crops grown under the organic input system (Figure 7), followed by the reduced input and high input systems. Crops grown under the annual grains rotation in the organic input system yielded significantly higher root colonization (18.5%), followed by those grown under the low diversity (10.8%) and grain/forage (10.5%) systems (Figure 2). In the reduced input system, crops grown in the low diversity had higher mycorrhizal root colonization (9.8%), followed by the grain/forage system (6.9%) and annual grains system (4.0). The opposite was true for crops grown under the high input system, where crops grown in the low diversity system had the lowest level of mycorrhizal root colonization (0.8%). This may be the result of greater number of tillage operations

Figure 7. Influemce of input levels and crop diversity on AMF colonizations (1997)

Site Characterization



Results clearly indicate there is some variability in the numbers and spatial distribution of the AMF propagules in the field site. There may be some differences in the influence that AMF fungi will have on root colonization of the various crops within a given area of the field. Our results are similar to those found by Talukdar and Germida (1993) where they reported 78 to 272 AMF spores per 100 g soil in field soils of Saskatchewan. Boyetchko and Tewari (1986) reported 11.5 spores per g dry soil (1150/100 g soil) from a barley field in north-central Alberta. These spore densities will differ according to cropping systems and types of crops grown in the field (i.e. cropping history). In addition, the methods for determining spore densities by the authors in Saskatchewan and Alberta may be an over-estimation since total spore counts (which include viable and dead spores) were taken. Our methods employed the use of MPN which accounts for the number of viable AMF spores only which would provide a more realistic value of the influence that viable AMF spores will have on the crops grown in the field.

Further analysis using multivariate analysis of soil and spore populations may provide additional information on the relationship between AMF spores (soil microbes) and soil properties and how these soil properties influence mycorrhizal fungi.

Annual AMF Root Colonization Evaluation

Legume and pulse crops such as alfalfa and peas are known to be very susceptible to mycorrhizal root colonization, while crops such as canola are known to be nonmycorrhizal. Our results showed that alflafa and peas had the highest levels of AMF in their roots, followed by cereals, with the oilseed crops (canola and flax) exhibiting little to no mycorrhizal root colonization.

Of the cereals evaluated, rye had the highest level of root colonization, followed by wheat and barley. Crops grown in the low diversity rotation yielded relatively high mycorrhizal root colonization, particularly because of the inclusion of lentils as a green manure fallow under the organic input system. In 1995, the grains/forage rotation system exhibited the highest level of AMF root colonization, but not in 1996. The reason for this is that lentils were not evaluated in 1995 while in 1996, lentils (which are included in the annual grains rotation) showed the highest levels of root colonization of all the crops evaluated.

Results from this study support the concept that low chemical input systems (such as organic systems) result in higher mycorrhizal root colonization compared to the reduced and high input systems. The annual grains crop rotation in the organic input system favors higher levels of AMF fungi because of the inclusion of lentils and peas in the rotation. However, in the annual grains rotation in the high and reduced input systems, crops such as canola and flax are relatively free of mycorrhizal fungi. This may be the reason why this rotation system in the high and reduced input systems yielded lower mycorrhizal root colonization than in the organic system.. The relatively high level of root colonization under the reduced input/low diversity rotation may be the result of fewer tillage operations during the course of the growing season, compared to the high input/low diversity rotation. It has been documented that tillage practices that result in site disturbance may have a detrimental effect on mycorrhizal fungi (McGonigle and Miller, 1993). The cropping system with the lowest mycorrhizal root colonization was the high input/low diversity rotation. However, weed control in the organic system required more tillage operations than the reduced input system, resulting in more site disturbance in the organic input system. Although Kucey and Paul (1983) reported that mycorrhizal spore populations are greater in undistrubed soils than in cultivated soils, Zak et al. (1982) suggested that the ability of AMF fungi to re-establish their mycorrhizal associations after soil disturbance may partially determine their success in a disturbed site. More research should be undertaken to understand the ability of mycorrhizal fungi to re-establish and effectively colonize plant roots in agroecosystems. It may be possible that ecotypesof known AMF fungi are adapted to certain agricultural cropping practices.

Under organic input systems, application of phosphorus is through the addition of the microbial inoculant Provide® while nitrogen is provided by legumes for their nitrogen-fixing properties. However, under the high and reduced input systems, fertilizers and chemical pesticides are utilized as part of the farm management system. Mycorrhizal fungi are known to improve the uptake of phosphorus and nitrogen, particularly under low fertility levels, and thus may permit efficient nutrient uptake into the plant. However, under the high and reduced input systems, higher levels of fertilizers and chemical pesticides are utilized as part of the farm management system. Higher use of fertilizers (particularly phosphorus) and some pesticides may have a detrimental effect on AMF fungi, thus resulting in lower levels of mycorrhizal root colonization in crops. However, more research is required to determine if high inputs of fertilizers and use of specific chemical pesticides are detrimental to mycorrhizal fungi. Since these fungi are ubiquitous in all soils, including agricultural soils, there may be mycorrhizal species that tolerate higher fertility levels and chemical pesticides.

Baltruschat and Dehne (1988) reported that AMF fungi are frequently found in intensively cultivated soils, but their populations vary with the crop rotation system and the intensity of fertilization. In the Scott study, the herbicides, Poast, Buctril M, and Mataven, and Vitavax (fungicide) were applied in the high and reduced input systems, yet mycorrhizal root colonization occurred in the crops (except canola and flax). One must therefore be cautious when making generalizations on the effect of chemical pesticides on mycorrhizal fungi. There are very few research studies which have documented any specific detrimental effects of specific chemical pesticides (fungicides, herbicides) on mycorrhizal fungi. Additional research focussing on the effects of various chemical pesticides (herbicides, fungicides, and insecticides) should provide information on the impact (negative, positive, or neutral) of these chemicals on mycorrhizal root colonization in agricultural cropping systems.

It should be borne in mind that this study has evaluated the effects of specific cropping practices at the Scott Experimental Farm only. Site-specific studies must be carefully examined, since mycorrhizal species differ from field to field, and amongst geographical locations. Although mycorrhizal fungi are considered to be non-host specific, research studies have provided evidence that the mycorrhizal fungus-host association may be somewhat host-specific, where differences may also occur amongst crop cultivars (Azcon and Ocampo, 1981; Boyetchko and Tewari, 1995; Hetrick et al., 1992). The degree of host-specificity in AMF fungi may determine the effectiveness of the mycorrhizal association and the degree to which cropping practices have an effect. Therefore, selection of various crop cultivars in any research study may have an influence on the amount of mycorrhizal root colonization in different crop rotations and input systems.

Although cropping practices did have an influence on the development of mycorrhizal root colonization in the crops evaluated, further estimation of the inoculum potential in the soil will have to be determined, particularly in year 6 of this study. Future studies should also determine if benefits to crops in these agroecosystems are through improved or efficient nutrient acquisition, reductions in root disease development, drought tolerance, or other mechanisms. For example, in one study, it was concluded that low levels of soil phosphorus were counterbalanced by greater mycorrhizal infection before grain filling period in winter wheat (Stöppler et al., 1990).

Disease Monitoring

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Rationale

Plant disease of field crops grown in Saskatchewan is a major factor contributing to yield and quality reduction. Diseases are influenced by the environment and by management practices, particularly crop inputs (including cultivar choice, fertility levels, fungicide application), crop rotation and tillage system.

Methods

Disease assessment scales used to quantify disease symptoms on all crops have been reported in previous annual reports from this study. The following discussion indicates changes in rating protocols among the years the data was collected.

From 1995 to 2000 foliar diseases (whole plant ratings) of barley and wheat were rated on a 0-11 scale (McFadden 1991) at the milk to soft dough stage. After 1998 more extensive disease assessment included fall rye and additional ratings of flag and penultimate leaves of cereals using the Horsfall-Barrett scale (1945), which were carried out at the flag leaf stage as well as the milk to soft dough stage on 20-25 plants/plot. Cereal root disease assessments were conducted by sampling roots, washing and evaluating the sub-crown internode using a 0-4 scale (Ledingham et al. 1973) in all years except 1998. Between 1995 and 1997, 50-100 subcrown internodes per plot were evaluated, while in 1999 and 2000, 25 subcrown internodes were assessed per plot.

Prior to 1998 observations revealed low levels of disease in field pea. In 1999 and 2000 a foliar mycosphaerella assessment was conducted prior to flowering on 5 sites/plot using a 0-9 scale (Xue 1997) followed by foliar and stem ratings for mycosphaerella blight every two weeks prior to physiological maturity (plant dry down) on 10 plants/plot. Stems of field pea plants were assessed based on degree of stem discoloration and girdling (Wang 1997). Pea root disease surveys were conducted at 3-4 weeks post emergence on 10 plants/plot using a 0-4 category scale (Hwang et al. 1994). Powdery mildew occurred only one year (1999) in an isolated region of one plot.

Incidence of blackleg in canola was measured from 1996 to 1997 and from 1999 to 2000. Between 1998 and 2000 the severity of blackleg basal stem lesions were evaluated on 50-100 plants/plot using a 0-5 scale (Newman 1984) just prior to swathing. Levels of sclerotinia infection were observed at trace levels only.

Fungicide applications were restricted to wheat and Harrington barley plots within the high input system in 1999. A single application of Tilt (propiconazole 125 g ai/ha) was applied at the flag leaf stage with 220 L/ha of water.

Results and Discussion

Climatic conditions for each of the years of the study and the long term average are found in Table 1. Generally 1997 and 1998 were considered 'dry' years and 1999 and 2000 were 'wet' years based on the precipitation received during the month of July.

Table 1. Precipitation and mean daily temperature recorded monthly during the growing season at Scott, SK from 1995 to 2000.

Monthly Precipitation Totals:

Month	1995	1996	1997	1998	1999	2000	Long
May	23	32	27	5	46	6	34
June	24	41	60	105	43	33	64
July	29	106	26	16	78	95	65
August	71	43	26	14	54	52	46

Mean daily temperature as measured at 1.5 m height.

Month	1995	1996	1997	1998	1999	2000	Long
May	11.2	8.0	8.4	13.9	9.9	9.7	10.3
June	16.7	15.3	15.4	14.4	14.3	13.9	14.5
July	16.7	17.0	17.8	18.0	15.1	17.4	17.2
August	14.7	17.7	17.5	19.4	16.8	15.8	16.0

* Long term normal based on Environment Canada data for Scott SK. 1961-90.

Wheat

Impact of Rotation Interval on Wheat Disease within the LOW Diversity System

Disease differences between crop phases within the LOW diversity system were examined only from 1998 to 2000 in order to allow a comparison between the three year rotation interval (phase 6), wheat on wheat (phase 3) and wheat on fallow (phase 2).

Results of whole plant ratings prior to crop dry down revealed there was no treatment by year interaction and no significant difference in whole plant disease ratings between crop phases. Although there was no treatment by year interaction, root rot ratings and incidence from 1999-2000 were affected by crop phase (Table 2). An input by phase interaction was also observed.

Table 2. Common root rot assessment (severity and incidence) of wheat in the LOW diversity system.

	fallow-wht	wht-wht	wht-GM-can-wht	fallow-wht	wht-wht	wht-GM-can-wht
	Ratings (0-4)			Incidence (%)		
Organic	0.9 bc	0.8 cd	0.7 cd	54 c	48 c	45 c
Reduced	0.6 d	0.6 d	0.7 cd	45 c	47 c	48 c
High	1.1 b	0.9 bc	1.7 a	61 b	51 c	76 a
Mean	0.9 b	0.8 b	1.1 a			

Phase mean value: LSD$_{0.05}$= 0.13

phase*input values followed by the same letter are not different (P=0.05)

Leaf spot disease assessment of wheat did not indicate great differences among the treatments. However a statistically significant difference was obtained within the LOW diversity system on penultimate leaves at the flag leaf stage. It indicated that severity was highest for wheat grown on wheat stubble followed next by wheat grown 3 years after the previous wheat and lowest for wheat on fallow (Table 3). Wheat on wheat also produced the greatest whole plant disease rating.

Table 3. Leaf spot disease assessment of wheat in the LOW diversity system.

Flag Leaf stage: Low diversity system Phase	Penultimate	Whole Plant
wheat on fallow	0.75 c	5.1 b
wheat on wheat	0.81 a	5.6 a
wheat 3 years after wheat	0.78 b	5.1 b
LSD$_{0.05}$	0.015	0.17

A significant year by input interaction for leaf spotting diseases on the flag and penultimate leaves in the LOW diversity system prior to the milk-soft dough stage revealed lower ratings in the high input system in 1999. This was a consequence of fungicide application in 1999 and not in 2000 (Table 4).

Table 4. Leaf spot disease symptoms on flag and penultimate leaves of wheat in 1999 and 2000. Disease symptoms assessed using the Horsfall-Barratt 0-11 scale.

	Flag		Penultimate	
	1999	2000	1999	2000
Organic	6.9 a	6.3	9.0 b	9.0
Reduced	7.5 a	6.8	9.9 a	9.2
High	4.2 b	6.1	7.2 c	8.9
LSD$_{0.05}$	0.7	1.2	0.7	0.7

On flag and penultimate leaves prior to the milk-soft dough stage in the Low diversity system a phase by input by year interaction was observed. A break down by year revealed the phase by input interaction was significant in each year. Ratings in 1999 revealed that fungicide application was very effective in reducing disease pressure most notably for wheat on wheat where ratings were comparable to wheat on fallow. When no fungicide was applied (2000) disease pressure for wheat on wheat in the high input system was higher than wheat on fallow (Table 5). These results confirm that fungicides are most effective when disease pressure is high as it was for wheat on wheat. This may be a treatment that should be monitored more closely for disease and targeted for fungicide application, especially in wet years.

Table 5. Leaf spot disease assessment on flag and penultimate leaves of wheat made at the soft-dough growth stage in the LOW diversity system in 1999 and 2000. Assessment made with the Horsfall-Barratt 0-11 scale. (Phase 2: wheat on fallow; 3: wheat on wheat; 6: wheat 3 years after wheat).

	Phase (1999)			Phase (2000)		
	2	3	6	2	3	6
		Flag Leaf			*Flag Leaf*	
Organic	6.5 b	7.1 b	7.0 b	6.2 c	6.7 b	6 cd
Reduced	7.3 ab	8.0 a	7.2 ab	6.9 ab	7.2 a	6.3 c
High	4.8 c	4.4 c	3.3 d	5.7 d	7.0 ab	5.8 d
		Penultimate Leaf			*Penultimate Leaf*	
Organic	8.6 c	9.2 bc	9.4 ab	8.9 bc	9.2 ab	8.8 bcd
Reduced	9.9 ab	10.1 a	9.7 ab	9.5 a	9.4 a	8.7 cd
High	7.7 d	7.4 d	6.4 e	8.4 d	9.4 a	8.9 bc

phase by input values within a year and crop stage followed by the same letter are not different (P=0.05)

Impact of Input and Diversity Level on Wheat Diseases

In 1995 no differences between treatments were observed as a rotation effect had not yet been established. Observations in 1996 revealed less foliar disease in wheat grown in the high input system (5.2 vs mean of 5.9 in organic and reduced) and lower incidence of common root rot in wheat from the reduced input system (27% vs 45% in high and organic). Analysis of whole plant ratings prior to plant dry down in wheat across levels of inputs and diversity was conducted using results from 1997-2000. A significant year by input and input by diversity by year interaction required separating the years into wet and dry years on the basis of July precipitation. The years 1997 and 1998 were considered dry with below normal July precipitation and 1999 and 2000 were considered wet with above nonnal July precipitation.

In dry years the average rating was 6.1 on a scale of 0-11 and in wet years reached the maximum of 11. However no significant differences were observed between treatments (diversity, input, diversity by input) in either wet or dry years.

Analysis of leaf spot symptoms on flag and penultimate leaves across years for different levels of inputs and diversity was conducted. Only input level was observed to impact on leaf spot disease pressure in wheat and only prior to crop dry down. The response difference observed between 1999 and 2000 was attributed to fungicide application in the high input system in 1999 (Table 6). In 1999 the disease pressure in the high input system was lower than either the organic or reduced input system. In 2000 flag leaf ratings in the high input system were found to be similar to those in the organic system with no differences observed among input levels for penultimate leaf ratings.

Table 6. Leaf spot disease assessment on flag and penultimate leaves of wheat made at the soft-dough growth stage in 1999 and 2000. Assessment made with the Horsfall-Barratt 0-11 scale.

	1999		2000	
	Flag	Penultimate	Flag	Penultimate
Organic	6.8 a	9.2 a	6.2 ab	9.0 a
Reduced	7.4 a	9.8 a	6.5 a	9.0 a
High	4.1 b	7.3 b	5.8 b	8.7 a
$LSD_{0.05}$	0.8	0.7	0.6	0.5

Barley

In 1996 foliar leaf spot symptoms on barley were slightly higher in the DAG diversity than in the DAP with no differences in common root rot between treatments. Whole plant ratings were conducted between 1997 and 2000 with an analyses across years revealing a unique diversity and input by diversity response among years (Table 7). When separated on the basis of above normal (wet) or below normal(dry) July precipitation no treatment differences were observed in wet years. Whole plant ratings averaged 9.2 on a scale of 0-11 in wet years. In dry years when less disease pressure was observed (average rating=7.8) greater disease pressure was present in the malt barley (cv. Harrington) of the DAG diversity than in feed barley (cv. Brier or AC Harper) grown in the DAP diversity system (P=0.10). Common root rot incidence measured in 1997, 1999 and 2000 indicated no treatment response.

Table 7. Leaf spot disease severity and incidence of barley in 1997 and 1998. Assessment made using the McFadden 0-11 scale.

Diversity	Whole Plant Rating (1997-1998)	Incidence (1997)
DAG	9.8	91.6
DAP	5.7	81.5
$LSD_{0.10}$	2.2	Not enough data

Leaf disease surveys conducted at the flag leaf stage and prior to maturity in 1999 and 2000 showed no evidence of treatment effects on flag leaf disease levels. However a year by input by diversity interaction on penultimate leaves both at the flag leaf and soft-dough growth stages was observed (Table 8). In 1999 penultimate ratings at the flag leaf stage revealed a slight reduction in leaf spot symptoms for barley grown in the organic-DAG system. A fungicide application on Harrington in the High input-DAG diversity system lowered disease pressure on the penultimate leaf later in the growing season relative to Harrington in the reduced input system. In 2000 slightly higher levels of disease were observed on penultimate leaves in the organic input system at the flag leaf stage than in the reduced or high input system. By August of 2000 disease pressure had increased dramatically and was most pronounced in the DAG diversity system. Less penultimate leaf disease pressure on Harrington in the organic diversity in 2000 could be attributed to less crop growth and a more open canopy than in the reduced or high input system.

Table 8. Leaf spot disease severity and incidence of barley in 1999 and 2000. Assessment made using the McFadden 0-11 scale. Numbers in brackets are disease incidence (%).

Barley penultimate	1999		2000	
Flag Leaf:	DAG	DAP	DAG	DAP
Organic	0.7 b (65)	0.9 a (88)	0.7 a (68)	0.4 b (43)
Reduced	0.9 a (93)	1.0 a (95)	0.03 c (3)	0.0 c (0)
High	1.0 a (95)	0.9 a (93)	0.03 c (3)	0.03 c (3)

Barley penultimate	1999 (incid=100)		2000 (incid=100)	
Prior to Maturity	DAG	DAP	DAG	DAP
Organic	3.0 ab	1.3 c	5.2 b	2.4 c
Reduced	3.5 a	2.8 ab	7.3 a	2.8 c
High	2.1 bc	2.0 bc	7.3 a	3.2 c

input*diversity values within a year, crop stage and leaf type followed by the same letter are not different (P=0.05)

Canola

In 1995 incidence of blackleg was very low in contrast to 1996 where blackleg pressure was greater and incidence higher in the organic input system than in the high or reduced input system (80% vs mean of 46% for reduced and high). Of the 2 diseases observed in canola between 1995 and 2000 blackleg was the most prevalent. Sclerotinia was observed on occasion however severity and incidence levels were very low. In general levels of blackleg infection were too low to have a major impact on yield. The highest blackleg severity levels were observed in 1999 reaching a maximum of 1.7 on a scale of 1-5.

Blackleg ratings in canola analysed between 1997 and 2000 revealed that the Brassica rapa canola cultivar grown in the Organic input system was more susceptible to blackleg infection than the B. napus cultivar grown in the reduced and high input system (Table 9).

Table 9. Mean blackleg severity (0-5 scale) and incidence (%) on canola in 1997 to 2000.

Input Level	BL rating (97-00)	BL Incidence (99-00)
Organic	1.0 a	44.2 a
Reduced	0.4 b	13.0 b
High	0.6 b	19.8 b
$LSD_{0.05}$	0.64	15.6

Values followed by the same letter are not different (P=0.05)

The analyses also revealed a significant year by input by diversity interaction. A break down on the basis of precipitation in July with dry years occurring in 1997 and 1998 and wet years in 1999 and 2000 revealed blackleg ratings increased from 0.63 in dry years to only 0.66 in wet years. In dry years no treatment effects or interactions were observed. In wet years higher blackleg ratings and incidence were observed in Brassica rapa of the organic input system than B. napus of the high or reduced input system. However the input by diversity interaction was different between 1999 and 2000 (Table 10). In 2000 blackleg infection and incidence of the HIGH and LOW diversity systems dropped considerably compared to levels observed in 1999 despite greater July precipitation. Less above ground biomass in 2000 and a more open canopy may have contributed to the reduction.

Table 10. Blackleg severity (0-5 scale) and incidence (%) of canola in 1999 and 2000.

	1999			2000		
Severity	LOW	DAG	DAP	LOW	DAG	DAP
Organic	1.7 a	1.5 a	1.7 a	0.7 b	plowed under	1.3 a
Reduced	1.1 b	0.5 cd	0.2 d	0.1 c	0 c	0 c
High	1.7 a	0.7 bc	0.5 cd	0.2 c	0.1 c	0.1 c

	1999			2000		
Incidence	LOW	DAG	DAP	LOW	DAG	DAP
Organic	53 a	51 a	53 a	44 b	plowed under	64 a
Reduced	39 b	21 cd	11 d	4 c	2 c	3 c
High	50 a	31 bc	19 d	10 c	3 c	7 c

Input by diversity values within a year followed by the same letter are not different (P=0.05)

Fall Rye

This crop was not assessed for disease symptoms until 1999. Fall rye disease ratings in 1999 and 2000 revealed input level and cropping diversity had no affect on flag, penultimate leaf or whole plant disease ratings. This lack of response can be attributed in part to poor establishment and thin stands. Ratings at the soft-dough growth stage had an average penultimate leaf rating of 4.1 on a scale of 0-11 and whole plant rating of 10.0. Root rot ratings averaged 1.0 on a scale of 0-4 with an average incidence of 45%.

Field Pea

The most prevalent disease of field pea observed in this study was mycosphaerella blight. Powdery mildew was observed only in an isolated area of one plot late in the growing season in 1999.

In 1995 and 1996 the level of disease pressure in field pea was low. Stem and foliar disease ratings on select pea plots in 1997 and 1998 prior to plant dry down showed no evidence of input level or cropping diversity affects with an average foliar rating of 3.6 and stem rating of 2.0 on a scale of 0-9. A complete disease assessment of all pea plots was conducted in 1999 and 2000 beginning in early July with additional surveys carried out every 2 weeks until plant dry down. Analyses across years however showed no measurable differences between treatment in early or mid July. Prior to the crop drying down a year by input interaction was observed for stem and root disease ratings (Table 11). A break down between years showed greater stem infections and root disease on field pea in the high input system than in the organic system in 1999. This may have been a function of higher biomass yields and a more closed canopy in the high input system. Lower biomass yields in 2000 likely reduced overall infection levels and contributed to little or no difference in stem infections and root disease between levels of inputs.

Table 11. Mycosphaerella blight (0-9 scale) and root rot (0-4 scale) disease rating of field pea in 1999 and 2000.

	1999		2000	
Pea	Stem Rating	Root Disease	Stem Rating	Root Disease
Organic	1.6 b	0.5 b	2	0.2
Reduced	2.3 ab	1.7 ab	2.6	0.4
High	3.2 a	2.3 a	2	0.3
$LSD=_{0.05}$	1	1.3	0.7	0.5

Conclusions

In general climatic variations from year to year had a greater impact on disease occurrence and severity than input level or cropping diversity. The greatest impact of input level decisions occurred in wheat and barley when fungicides were applied in the high input system in 1999 reducing disease on flag and penultimate leaves in wheat and penultimate leaves of barley. Differences in disease severity in barley between cropping diversities and in canola between levels of inputs were primarily a function of variety selection due to differences in disease resistance. Although in the case of canola a later seeding date for Brassica rapa (organic) than B. napus (high and reduced) would also have been a factor. Despite higher levels of disease within wheat phases of the LOW diversity system resulting from tighter wheat intervals within the 6 year rotation a comparison across diversity levels showed cropping diversity systems had no impact on levels of disease in wheat. Not surprisingly six year cropping intervals for pea, barley, fall rye and canola in each of the 3 cropping diversities were effective in minimizing levels of infection. These results demonstrate that the impact of disease pressure on yield in the first six year rotation cycle was minor compared to other variables such as soil moisture or nutrients.

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Assessment of Leaf Spotting Pathogens in Wheat, Barley and Fall Rye

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Rationale

Assessment of leaf spots in cereals involves measuring the severity of symptoms and identifying the causal agents. There are several fungi that can cause leaf spotting diseases in wheat and barley, many of which cannot be easily identified based on visual symptoms. Therefore, incubation of diseased leaves on nutrient agar is necessary for a proper identification. In western Canada, among the most common leaf spotting pathogens in wheat are Pyrenophora tritici-repentis (tan spot), Cochliobolus sativus (spot blotch), Mycosphaerella graminicola (Septoria tritici blotch), Phaeosphaeria nodorum (Stagonospora nodorum blotch) and P. avenaria f. sp. triticea (Stagonospora avenae blotch). In barley, the most common leaf spotting pathogens are Pyrenophora teres (net blotch), C. sativus, Rhynchosporium secalis (scald) and P. nodorum and P. avenaria f. sp. triticea (Stagonospora blotches).

Although some cereal cultivars are susceptible mostly to only one leaf spotting pathogen, the majority are susceptible to several in different degrees. Cultivars susceptible to an array of leaf spotting pathogens are good 'indicators' of environmental and management effects on the relative prevalence of pathogens.

In addition to cultivar, the prevalence of leaf spotting pathogens could be affected by weather, location, and crop management practices. A differential effect on the pathogen populations by any of these factors might be reflected on changes in the severity of infection.

Methods

Leaves collected from each of the treatments at the milk stage were dried at room temperature. Leaf pieces of about 1 cm2 were selected randomly from lesions from each of 15-20 upper leaves taken at random from each plot at the time disease severity was assessed. Leaf pieces were surface-desinfected, plated on PDA and incubated for 5-7 days. Percent isolation of the fungi based on the total leaf area colonized by each was calculated for each plot.

Results and Discussion

Tables 1 and 2 show the mean percent isolation of each of the leaf spotting pathogens from AC Barrie, Brier and Harrington. In AC Barrie, the most commonly isolated leaf spotting pathogens were P. tritici-repentis, P. nodorum and M. graminicola (Table 1). The prevalence of these fungi varied significantly among years. P. tritici-repentis was the most prevalent pathogen in 1998 but was less commonly isolated in 1999 and 2000. The prevalence of M. graminicola increased from 1998 to 2000. In the latter, most leaf spot lesions were caused by M. graminicola. The prevalence of tan spot over the Septoria and Stagonospora leaf blotches in 1998 can be attributed to low precipitation and high temperature during plant growth which would not have favoured the development of the latter diseases. On the other hand, the increased levels of M. graminicola in 1999 and 2000 could be related to the higher than normal precipitation, especially in 2000, and lower temperatures than in 1998.

Harrington was colonized mostly by P. teres and there were no differences among years in the relative prevalence of this pathogen (Table 2). It was also the most commonly isolated fungus from Brier, however other pathogens isolated represented up to half of the leaf area affected. There was also a change in the prevalence of leaf spotting pathogens in Brier among years. For example, C. sativus was isolated more frequently in 1999 and 2000, the years with the highest amounts of precipitation, whereas R. secalis was most common in 1998 when there were high levels of precipitation early in the season.

Treatment (input/diversity) effects on the relative prevalence of leaf spotting pathogens were not significant for any of the wheat or barley cultivars.

Table 1. Mean percent isolation of leaf spotting pathogens from the common wheat cultivar AC Barrie in 1998-2000.

Leaf Spotting Pathogen	% isolation		
	1998	1999	2000
P. tritici-repentis (tan spot)	56	23	7
P. nodorum (Stagonospora nodorum blotch)	22	31	7
M. graminicola (Septoria tritici blotch)	12	42	79

Table 2. Mean percent isolation of leaf spotting pathogens from the barley cultivars Brier and Harrington in 1997-2000.

Cultivar/leaf Spotting Pathogen	% isolation			
	1997	1998	1999	2000
Brier				
P. teres (net blotch)	77	49	42	54
C. sativus (spot blotch)	0	15	26	24
R. secalis (scald)	6	23	0	0
P. nodorum (Stagonospora nodorum blotch)	15	9	8	7
P. avenaria f.sp. *triticea* (Stagonospora avenae blotch)	1	0	18	12
Harrington				
P. teres (net blotch)	94	97	96	99
C. sativus (spot blotch)	0	0	2	0
R. secalis (scald)	5	3	0	1

Conclusions

The leaf spotting pathogen populations in the cereal crops grown in this study were successfully characterized. Changes in the relative prevalence of the leaf spotting pathogens were associated with environmental conditions, but not with diversity/input levels. Among the factors that could be affecting the lack of a difference in the prevalence of pathogens among treatments are low/high disease pressure, airborne inoculum, and presence of alternative hosts.

Future Work

Based on the results obtained in 1997-2000, we conclude that a detailed assessment of leaf spotting pathogen populations continue being done in cereal varieties that are susceptible to an array of pathogens and where we might be able to identify a treatment and/or environmental effect.

We also propose that, in addition to continuing with the identification of leaf spotting pathogens, fungal isolations from infected roots be done to determine treatment effects on root rotting pathogen populations.

Alternative Cropping Systems

ACS Long-Term Agro-Ecosystem
Research for the Canadian
1994 - 2012 Prairie Ecozone
Research Farm
Scott, Saskatchewan

Residual Weed Communities

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Rationale

Sustainable land management is based on five pillars: productivity, security, protection, viability, and acceptability (Smyth and Dumanski 1993). The successful management of weed populations contributes to the five pillars for sustainability of arable crop production systems. The development and adoption of integrated management tactics for weed populations are limited by our current knowledge of how the weed community is influenced by the management practices involved in crop production systems. The Scott Alternative Cropping System Project was designed to evaluate the sustainability of crop production systems using a 16 ha experimental study site for a minimum of 18 years. The experimental framework is a matrix of three input levels and three cropping diversity levels. Combinations of input and diversity levels result in nine cropping systems. We hypothesized that differences in weed community composition would be expected in the nine cropping systems during the six-year rotational cycle because species are known to respond to alterations in tillage and herbicide inputs, competitiveness of crops grown in the rotations, and yearly variation in growing season precipitation.

Methods

Cropping Systems

The nine cropping systems in the ACS study can be visualized as a three by three matrix of input levels and cropping diversity. The study consists of four replicates in a split-split plot design. The input levels are the main plots and cropping diversity levels are sub-plots. Each phase of each six-year rotation is present as sub-sub-plots.

The low diversity rotation (LOW) is a traditional rotation of fallow-wheat-wheat-fallow-canola-wheat. The organic input level uses green manure fallow, the reduced input level has one green manure fallow and one chemical fallow, and the high input level has tillage fallow. The diversified annual grains rotation (DAG) has a diversity of cereal, oilseed and pulse grains. The reduced and high input systems follow the same rotation (canola-fall rye-pea-barley-flax-wheat), while the organic input system incorporates green manure fallow for nitrogen fixation (green manure fallow-wheat-pea-barley-green manure fallow-canola). The diversified annual and perennial rotation (DAP) mixes grains and perennials (canola-wheat-barley-oat under seeded to brome alfalfa-brome alfalfa-brome alfalfa).

Differences in weed management strategies for the three input levels are summarized in Fig. 1. Tillage operations are presented as average values per plot per year. Mounted tine harrows and trailed rod were not counted as separate tillage operations. Seeding and fertilizer banding were not included as tillage operations. Herbicide applications are presented as average values per plot per year. Tank-mixed herbicides were considered one application. The annual input intensity per plot per year is the sum of the tillage operations and the herbicide applications. Only tillage was used for weed management in organic systems (ORG), whereas herbicides were used almost exclusively in the reduced systems (RED). Both tillage and herbicides were used for weed management in high input systems (HIGH). Annual input intensity was highest in the LOW crop diversity systems and lowest in the DAP system.

Weed Assessments

The residual weeds remaining in the plots after in-crop treatment were counted each year from 1994 to 2000. 1994 was the site characterization year in which the entire site was seeded to barley and treated uniformly. Each year, the weeds were identified and counted in twenty 0.5 m by 0.5 m quadrats in each of the 216 plots. Five quadrats were placed randomly within each quarter of the plot.

Analyses

The frequency of each species occurring more than once from 1994 to 2000 is reported for each year to illustrate the change in the overall weed community at the site.. Frequency is calculated as the percentage of the 216 plots in which the species were present. Graphs were also prepared to show the change in total weed density, species richness (number of different species per plot) and density of a few selected species in each of the systems over time.

The direction of change of the weed communities in each of the nine treatments is compared using principal response curves (Van den Brink and ter Braak 1997) created using the program CANOCO (ter Braak and Šmilauer 1998). This variation on traditional multivariate ordination techniques allows a clear representation of change due to cropping system over time by removing variation due to year and initial spatial factors. Principal response curves are based on redundancy analysis, a constrained form of principal components analysis (ter Braak 1995). In this type of multivariate technique, weed species densities are constrained to be linear combinations of the interaction of system and year. The log abundance (ln x+1) of all 48 commonly occurring speciesare included in the analysis. Year is removed as a covariable. Also, sub-plot is removed as a covariable to remove any initial spatial variation. The interactions between year and the high input low diversity rotation are not included as constraints in the analysis, allowing this system to be used as a reference point. Therefore, change in weed communities in each system is compared against the change observed in the high input low diversity rotation. Monte Carlo permutation tests were carried out to test whether the axes explained more variance than expected. Permutations of treatments were restricted to replicate block to account for the original experimental structure.

A principal response curve is a graph of canonical coefficients for one axis of the redundancy analysis versus time. Alone, this graph indicates the relative difference in the weed community associated with each system as compared to the reference system. The species scores, presented to the right of the principal response curve, enable the reader to determine the relative influence of each species on the principal response curve. Species with the highest absolute values have the largest influence on the trends illustrated in the principal response curve. Species with absolute values less than one are not included on the diagrams in this paper. The log-difference between the weed densities in the control and each system in each year can be determined for each species by multiplying the species score by the desired canonical coefficient.

Results and Discussion

The majority of species found on the experimental site either increased in frequency or remained relatively constant from 1994 to 2000 (Table 1). In 1994, only wild oats, wild buckwheat and lamb's-quarters were found in more than 50% of the plots. By 2000, seven species were found in greater than 50% of the plots. Lamb's-quarters, wild buckwheat, stinkweed and green foxtail were the dominate species. Stinkweed, pigweed species (redroot, tumble and prostrate) and flixweed had the largest consistent increase in density over time. Volunteer crops introduced on the site by the experiment also increased in frequency. Volunteer barley decreased in frequency over the experimental period. The entire site was cropped to barley in both 1993 and 1994, leading to high numbers of volunteers in the first few years on the experiment. Dandelion and foxtail barley also decreased in frequency after the initiation of the experiment. Therefore, the implementation of the cropping systems has altered the relative composition of the weed community on the experimental site.

Residual weed densities were very low in the site characterization year (Fig. 2). In general, weed densities increased from 1994 to 1997 in all nine systems, decreased until 1999 and then increased greatly in 2000. This pattern of high and low densities on the site is correlated with the amount of precipitation received in July and August of the previous year (Fig. 3). Normal or above-normal precipitation may increase seed production and increase the size of the weed seedbank in the soil. Drier than normal conditions in July and August may result in a reduction of weed seed production and fewer seedlings are recruited the following year. If precipitation in June is higher than normal in the next growing season, many seedlings are recruited from the seedbank and controlled by in-crop weed management. The lowest densities were recorded in the high input system with low cropping diversity and the highest weed density in the three organic input systems. Weed diversity was approximately five species per plot at the beginning of the study and increased to ten per plot in 2000 (Fig. 4). The three high input systems tended tohave the least number of species per plot.

The multivariate analysis based on RDA explained 41.7% of the variance in the weed community data set. Assessment date (year) and the weed distribution patterns (spatial) accounted for 33.0% and 49.1% of the total explained variance respectively. The treatment structure (systems) accounted for the remainder of the explained variance (17.9%). Two of the 56 axes were significant and explained 10.3 % of the variance.

Changes in treatment effects through time are clearly shown in the PRC diagrams for axis 1 (Fig. 5) and axis 2 (Fig. 6). The response curve for the reference treatment coincides with the horizontal axis. The PRC diagram for the first axis shows that species composition was similar at the start of the study but changed when the management practices for each system were applied (Fig 7). The largest relative differences in the weed community were found between the reference treatment and the three organic systems and these differences persisted throughout the six years. The curves for the organic systems suggest that the relative differences peaked in 1997 and then remained more or less constant for the next three years of the study. The weed community in the high and reduced input systems closely resembled the reference system.

Weights for species indicate the likelihood that a weed follows the fitted response of the whole community as displayed in a PRC diagram. A positive weight indicates a response pattern consistent with that displayed in the diagram for the overall community and a negative weight indicates an opposite response. The high positive species weights for green foxtail, lamb's-quarters, and stinkweed indicate that the relative contribution of these species to the observed pattern in the weed community is large (Fig. 5). The density of these species is higher from 1997 to 2000 than in the first and second year of the rotation. The density patterns for green foxtail and lamb's-quarters were similar with a drop in density in 1999 whereas stinkweed density dropped in 1998 (Fig. 7). The density patterns for wild buckwheat and redroot pigweed were similar to the previous three species but densities were <10 plants m-2 (data not shown).

The PRC diagram for the second axis shows a different and more complex response of the weed community over time than did the diagram for the first axis (Fig. 8). The consistent trend identified across the first six years is a pattern of increasing differences between the reference system and the three reduced input systems. The species that are increasing in the reduced input system also initially increased in the organic systems, peaking in 1997. After 1997, in the LOW and DAP organic systems, these species decreased to moderate levels; however, in the organic DAG systems the high populations were maintained. The most important species on this axis is wild oats. The densities of this species in the reduced and organic systems follow the trends indicated by the second PRC (Fig. 7). Narrow-leaved hawk's-beard densities contributed to the pattern in the reduced input systems observed on the second PRC. Narrow-leaved hawk's-beard densities increased in the reduced input DAP system until a peak in 1999. In 2000, the narrow-leaved hawk's-beard population in this system decreased to a level similar to that observed in 1997. Narrow-leaved hawk's-beard densities began to increase in the other reduced systems in 1999 and continued to increase in 2000. Change in shepherd's-purse densities did not occur in any systems until 1999 with further increases in 2000. The largest change was observed in the reduced DAP system, but this species increased in all reduced systems. This species increased in the high input DAP and DAG systems, and may be partially responsible for the recent differences between these systems and the reference system illustrated on the second PRC. The increase in shepherd's-purse in the organic DAP system does not appear to be reflected on the PRC. The relatively small increase in the density of shepherd's-purse is not as important to this system as the large increase in green foxtail in 2000.

The PRC analysis identified problematic weed species associated with the cropping systems after six years. Green foxtail, lamb's-quarters and stinkweed were abundant in the three organic input systems. Wild oats, shepherd's-purse and narrow-leaved hawk's-beard were abundant in the reduced input systems. The three organic systems appear to have reached equilibrium after a three-year transition period. The problematic weed species in the reduced systems still appear to be increasing after six years. The research shows the value of assessing weed densities annually and the need to continue weed assessments for the next six-year cycle.

Acknowledgements

The timing of weed assessments is closely linked with field operations and we are much indebted to Larry Sproule for keeping us informed of daily activities at the site. We are grateful to Robin Wise, Brenda Frick and Barb Gradin for organizing and conducting weed assessments from 1994 to 1999 and to the numerous members of the summer weed team who spent many hours counting weeds.

Table 1. Frequency (%) of commonly occurring weeds. Names of weeds from Darbyshire et al. 2000.

Common Name	Scientific Name	1994	1995	1996	1997	1998	1999	2000
Lamb's-quarters	*Chenopodium album* L.	61.1	79.6	87.5	70.4	82.4	76.9	96.3
Wild buckwheat	*Polygonum convolvulus* L.	64.4	62.5	75.9	72.2	55.6	87.0	96.3
Stinkweed	*Thlaspi arvense* L.	25.9	59.7	72.2	71.8	58.8	89.8	90.3
Wild oats	*Avena fatua* L.	72.2	27.3	52.3	57.4	60.2	63.4	67.6
Green foxtail	*Setaria viridis* (L.) P. Beauv.	45.4	27.8	57.4	72.2	49.5	56.5	74.1
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	20.4	25.0	46.3	42.1	14.4	42.6	59.3
Dandelion	*Taraxacum officinale* G. H. Weber (*ex* Wiggers)	45.4	53.2	30.6	32.4	23.6	27.3	26.9
Narrow-leaved hawk's-beard	*Crepis tectorum* L.	7.9	37.5	27.3	28.2	21.8	41.2	44.9
Redroot pigweed	*Amaranthus retroflexus* L.	9.7	12.5	13.4	28.2	23.1	52.3	66.2
Volunteer barley	*Hordeum vulgare* L.	—	53.2	52.8	25.9	17.1	10.6	16.7
Prostrate knotweed	*Polygonum aviculare* L.	16.7	29.2	23.6	24.5	12.5	31.0	27.3
Volunteer wheat	*Triticum aestivum* L.	36.6	6.9	20.4	31.5	26.9	13.0	27.8
Volunteer canola	*Brassica napus* L. and *B. rapa* L.	3.7	13.0	19.0	25.0	17.1	21.8	38.4
Flixweed	*Descurainia sophia* (L.) Webb (*ex* Prantl)	1.9	14.4	8.3	18.1	9.7	20.4	27.3
Canada thistle	*Cirsium arvense* (L.) Scop.	7.9	12.0	11.1	14.8	15.3	15.3	14.4
Prostrate pigweed	*Amaranthus blitoides* S. Watson	1.4	3.2	12.0	11.6	0.9	31.0	25.5
Tumble pigweed	*Amaranthus albus* L.	—	—	0.5	9.7	10.2	25.9	27.8
Volunteer flax	*Linum usitatissimum* L.	0.5	1.9	9.3	11.1	3.2	3.2	23.1
Russian thistle	*Salsola kali* L. subsp. *ruthenica* (Iljin) Soó	6.0	5.6	2.3	4.2	10.2	10.6	11.1
Volunteer alfalfa	*Medicago sativa* L.	0.5	6.5	4.2	4.2	5.1	8.8	16.7
Perennial sow-thistle	*Sonchus arvensis* L.	1.4	1.4	4.6	10.2	3.7	6.9	8.8
Common pepper-grass	*Lepidium densiflorum* Schrad.	1.4	1.4	2.3	2.3	6.5	7.9	8.8
Volunteer lentils	*Lens culinaris* Medic.	2.3	0.9	1.9	1.9	0.5	1.9	17.6
Volunteer fall rye	*Secale cereale* L.	—	—	1.9	4.6	4.6	3.2	12.0
Volunteer peas	*Pisum arvense* L.	—	0.9	7.9	1.4	4.2	6.9	4.6
Foxtail barley	*Hordeum jubatum* L.	18.1	0.5	—	1.4	2.8	—	1.4
Smooth brome	*Bromus inermis* Leyss.	—	—	—	—	0.5	6.0	8.3
Wild mustard	*Sinapis arvensis* L.	—	—	—	—	0.5	4.2	9.7
Wild tomato	*Solanum triflorum* Nutt.	—	1.9	3.2	1.9	0.9	1.4	0.5

Continued on next page

Common Name	Scientific Name	1994	1995	1996	1997	1998	1999	2000
American vetch	*Vicia americana* Muhl. *ex* Willd.	6.0	—	0.9	1.4	0.5	0.9	4.2
Annual sow-thistle	*Sonchus oleraceus* L.	2.3	5.1	—	—	—	—	—
Purslane	*Portulaca oleracea* L.	—	—	—	0.5	1.4	2.3	2.8
Canada fleabane	*Conyza canadensis* (L.) Cronquist	—	1.4	0.5	2.3	—	1.4	—
Yellow sweet-clover	*Melilotus officinalis* (L.) Pall.	—	—	—	—	0.5	0.9	3.2
Goat's-beard	*Tragopogon dubius* Scop.	0.9	2.3	0.5	—	—	—	0.5
Pale smartweed	*Polygonum lapathifolium* L.	—	0.5	0.9	—	—	0.5	2.3
Cleavers	*Galium aparine* L.	0.5	—	—	2.8	—	—	—
Cow cockle	*Vaccaria hispanica* (Mill.) Rauschert	—	—	0.9	1.4	—	—	0.9
Quack grass	*Elytrigia repens* (L.) Desv. (*ex* B. D. Jacks)	0.5	—	—	—	0.5	0.5	0.9
Pineappleweed	*Matricaria discoidea* D.C.	—	—	0.5	—	—	0.9	0.5
Sticky willowherb	*Epilobium ciliatum* Raf.	—	—	—	—	—	0.5	1.4
Bluebur	*Lappula squarrosa* (Retz.) Dumort.	—	0.9	—	0.5	—	—	—
Volunteer oats	*Avena sativa* L.	—	0.5	—	0.9	—	—	—
Rough cinquefoil	*Potentilla norvegica* L.	—	—	—	0.5	—	—	0.5
Prickly lettuce	*Lactuca serriola* L.	—	—	—	—	—	0.9	—
Pygmyflower	*Androsace septentrionalis* L.	—	0.9	—	—	—	—	—
Rose species	*Rosa* species	—	—	—	0.9	—	—	—
Biennial wormwood	*Artemisia biennis* Willd.	—	—	—	—	—	0.5	0.5

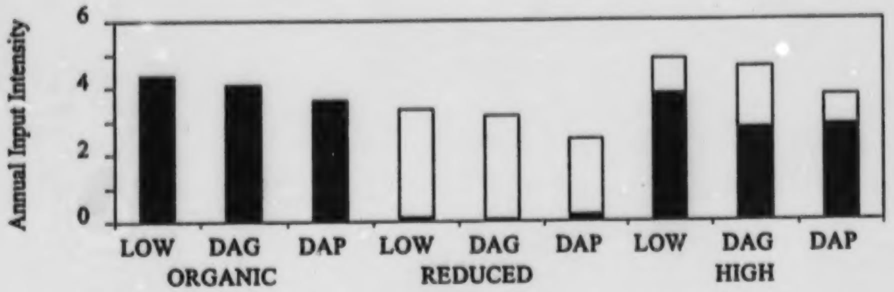

Figure 1. Number of herbicide applications (☐) and tillage operations (■) per plot per year.

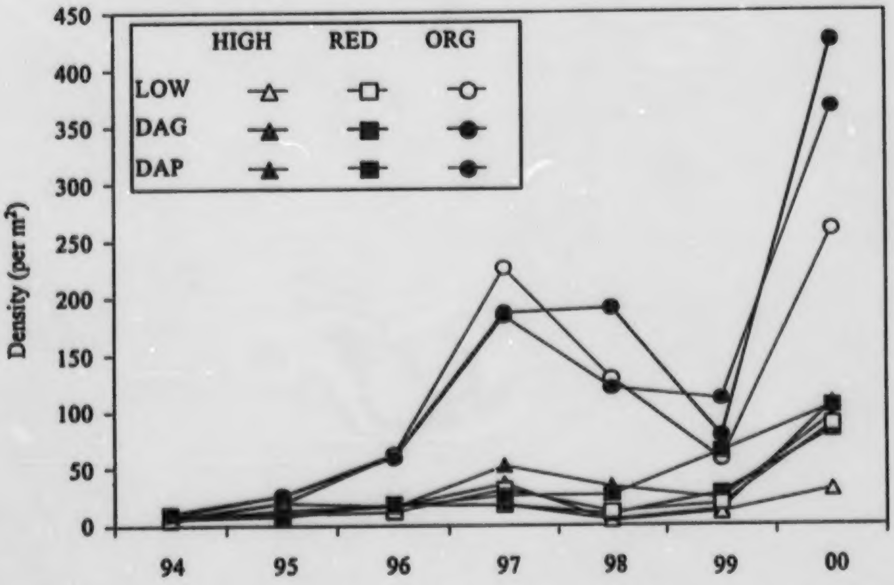

Figure 2. Total weed density in nine alternative cropping systems from 1994 to 2000.

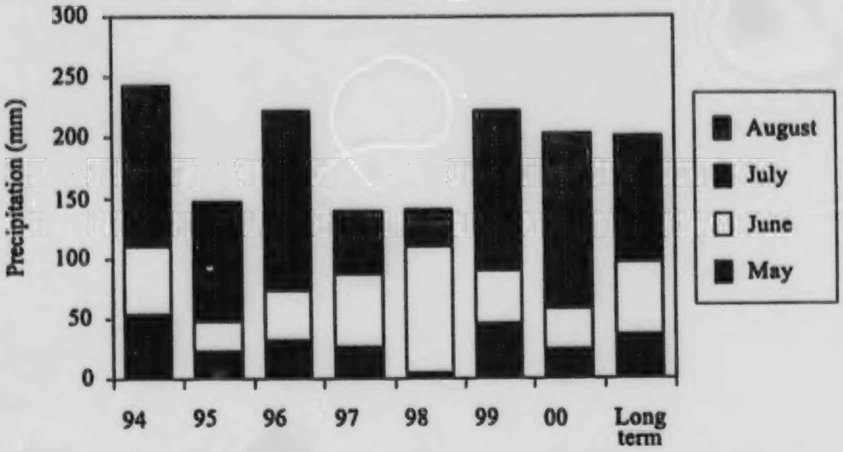

Figure 3. Precipitation in May, June, July and August at site from 1994 to 2000.

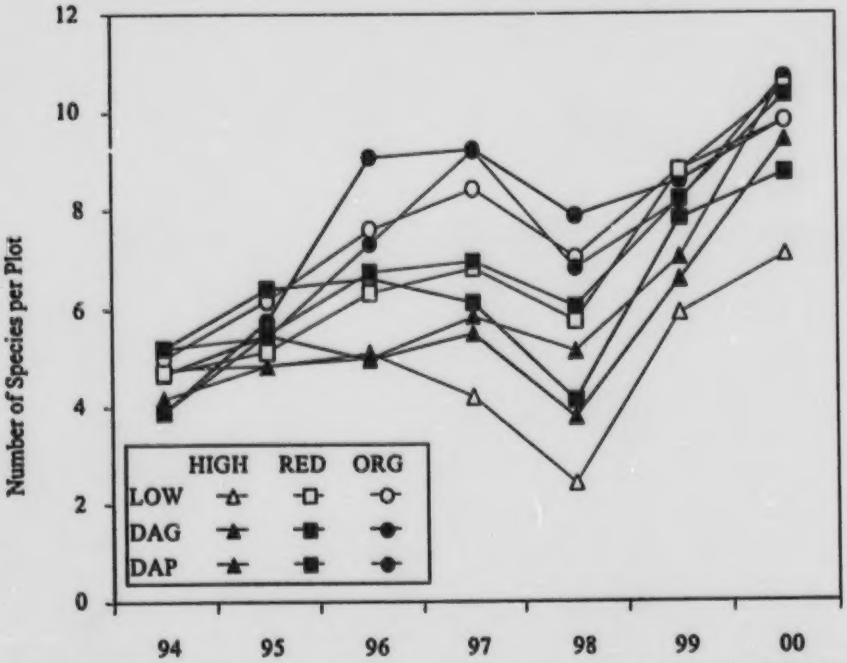

Figure 4. Weed species richness in nine alternative cropping systems from 1994 to 2000.

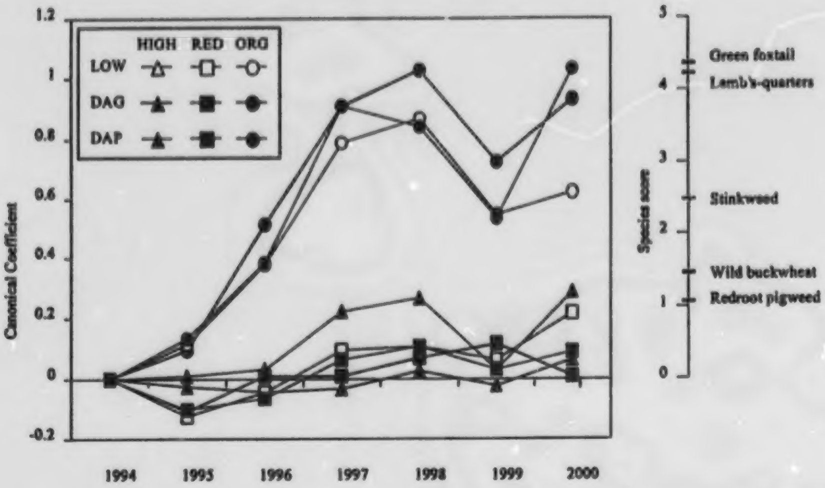

Figure 5. Principal response curve for first axis indicating the effects of alternative cropping system on weed community over time. This axis accounts for 44% of the treatment variance ($P \geq 0.001$).

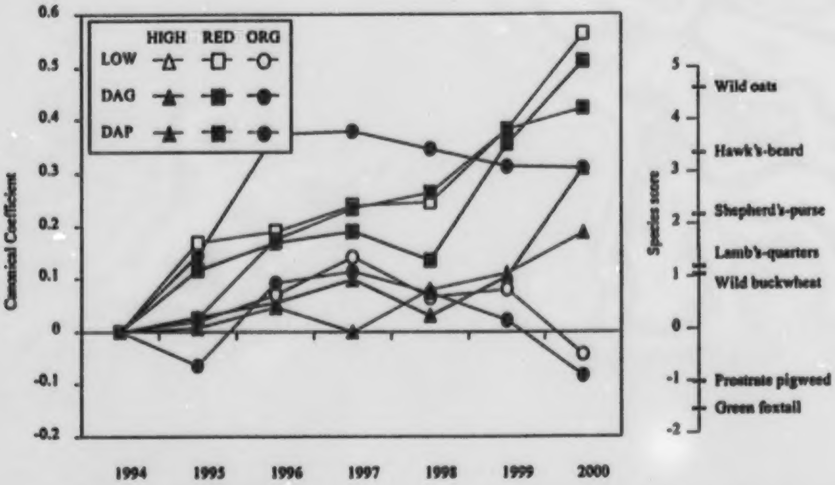

Figure 6. Principal response curve for second axis indicating the effects of alternative cropping system on weed community over time. This axis accounts for 13% of the treatment variance ($P \geq 0.001$).

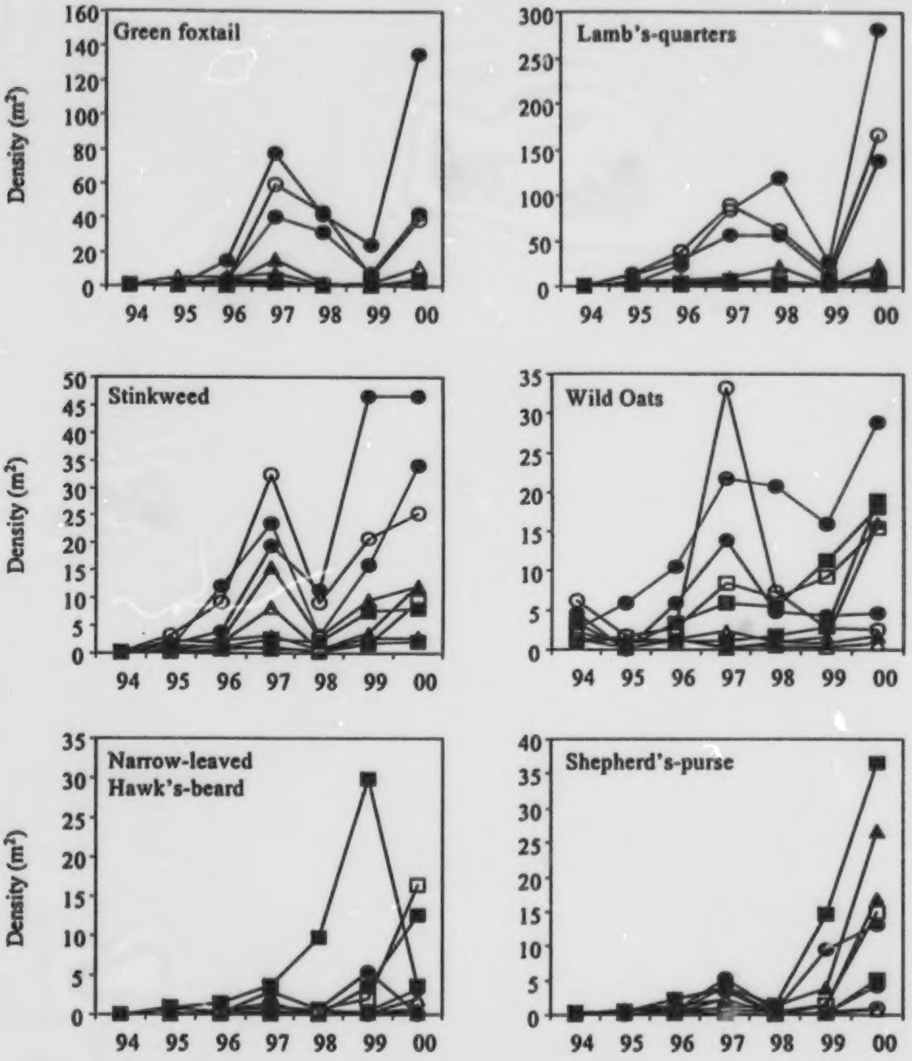

Figure 7. Weed density for green foxtail, lamb's-quarters, stinkweed, wild oats, narrow-leaved hawk's-beard, and shepherd's-purse in nine alternative cropping systems from 1994 to 2000. Note the density scale differs between species. Systems symbols are the same as Fig. 8.

Alternative Cropping Systems

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Weed Biomass

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Rationale

Production practices have changed dramatically over the last 20 years with the adoption of minimum or zero tillage cropping systems and the introduction of pulse and specialty crops. In recent years increased consumer demand and higher prices for organically grown produce has spurred a move back to a tillage-only based system by organic producers. For conventional producers low commodity prices and higher input costs has forced many farmers to look for ways to reduce weed control inputs to remain economically viable. Factors such as weed competition are bound to be affected by these changes which in turn will have a direct impact on the agronomic and economic performance of the adopted land management system. Determination of weed biomass on a systems level provides a measure of weed competition that assists in the process of evaluating a systems sustainability. It also acts as a tool for identifying causes of increased weed competition and provides possible management solutions to reduce weed growth and enhance a systems productivity and economic viability.

Methods

A long term alternative crops study was initiated at Scott in 1995 with input level as main plots and cropping diversity as the split plot. For detailed information on each of the nine cropping systems refer to the section 'Review of Study Design'.

Weed biomass was measured in annual crops near the time of crop maturity as an indicator of weed competition from 1996 to 2000. In the LOW diversity system weed biomass was measured in 4 of the 6 crop phases where the remaining two phases were fallowed. Within the DAG diversity weed biomass was measured in all phases except the 2 green manure fallow phases of the Organic input system. In the DAP diversity weed biomass was measured in only the first 3 phases for each level of input with the latter 3 phases of the diversity harvested as forage crops. Near the time the crop would be ready for swathing two above ground biomass samples were collected by cutting crop and weeds near the soil surface from 1 m2 areas located in diagonal corners of each plot. The two samples were then bulked and weeds separated from crop material. The weed sample was then dried and weighed to determine weed biomass yield. In the Organic input system weeds were further separated into categories of grassy, broadleaf and volunteer weeds prior to drying. Determination of biomass on the basis of weed type was conducted in all years between 1996 and 2000 except 1999.

Weed control strategies within each system were primarily a function of the constraints imposed by each level of input. To compare management strategies among systems weed control measures were separated on the basis of tillage operations and herbicide applications and whether they occurred prior to seeding or after seeding. Pre-seeding operations included any operations that occurred between harvest of the previous crop and seeding of the next crop. Post seed weed control operations consisted of both pre-emerge and in-crop operations. In the Organic input system where seeding occurred near the end of May weeds were controlled solely through the use of tillage. In-crop harrowing in the Organic input system was limited to larger seeded crops such as wheat, peas, and barley. In the Reduced and High input system seeding generally occurred near the middle of May. Pre-seed weed control in the High input system consisted primarily of tillage while in the Reduced input system herbicides were predominantly used. In-crop weed control in both the High and Reduced input system was accomplished through the use of herbicides. An additional weed control measure included the collection of chaff from annual crops within the Reduced input system and from the barley, canola, and wheat plots in the DAP diversity of the Organic input system.

Calculations of weed control operation intensities were based on the following criteria;

- Tillage performed primarily for weed control where the soil was not disturbed for at least 3 days prior was counted as a full tillage operation (eg. Most cultivations and in-crop harrowing).
- Tillage for soil finishing, seedbed preparation or to enhance weed control was counted as 0.5 operations if done simultaneously to a weed control tillage (eg. Mounted tine harrows, trailed rod weeder) or 0.75 operations if done separately (eg harrows, packers or harrow packers).
- Each pass with a sprayer was counted, even though more than one pesticide may have been applied as a tank mix.
- Operations between harvest of the previous year and seeding were categorized as pre-seed. Operations between seeding and harvest in the current year were categorized as in-crop.

Results and Discussion

Impact of Input Level Decisions and Cropping Diversity

As an aid to understanding weed biomass differences observed between systems weed control operations between 1995 and 2000 were separated on the basis of timing which included pre-seed and in-crop weed control and wether they were tillage operations or herbicide applications (Fig 1). An overall summary of annual weed control operations in each of the nine systems revealed sole reliance on tillage in the Organic input system, herbicide use in the Reduced and primarily tillage use in the High input system. In the pre-seed period the Reduced input system which relied primarily on herbicide use possessed the lowest operation intensities. Tillage use in the High and Organic input system was required more frequently. Generally higher tillage use in the DAP diversity could be attributed to problems with forage establishment and the weed control operations associated with the re-seeding operations. Far more important in the control of pre-harvest weed biomass were post-seed weed control operations (Fig.1). Less weed biomass in the Reduced and High input systems then in the Organic (Fig. 2) could be attributed in part to an additional 1.4 post seed weed control operations, the majority of which were herbicide applications. The low operations intensity in the Organic input system could be attributed to the short window of opportunity after seeding where tillage could be conducted without damaging the crop and to the fact that in crop harrowing was limited to larger seeded crops. Combining pre-seed and in-crop operations showed the High input system received on average 1.4 more weed control operations per year then either the Organic or Reduced input system. Little difference in weed biomass between the Reduced and High input systems (Fig. 2) of the DAG diversity suggests that the additional pre-seed operations, which were primarily pre-seed tillage operations did not reduce weed biomass in the DAG diversity. Summarised results showed very little difference in weed control operations among cropping diversities within input levels.

Figure 2 illustrates average annual levels of weed biomass in each of the nine systems and the relative contribution of each crop. Among input levels weed biomass was highest in the Organic input system. Greater weed biomass in the DAG diversity then either the LOW or DAP diversity in the Organic input system occurred as a result of increased weed growth in barley, and pea phases. Greater weed growth in barley of the Organic-DAG system could be attributed to under seeding barley to sweet clover which precluded the use of post emerge harrow operations to control weeds. In 1998 dry conditions hindered the establishment of sweet clover and reduced crop competition leading to an average weed biomass of 1039 kg/ha compared to a mean of 196 kg/ha in 1996, 1997, 1999 and 2000. Weed growth in peas of the ORG-DAG system was highly variable. The highest weed biomass in peas, 1840 kg/ha was recorded in 1996 when wet conditions promoted weed growth and reduced the effectiveness of tillage operations. In 1998 dry conditions following seeding greatly enhanced the effectiveness of weed control operations resulting in no measurable weed biomass being recorded. Improved weed management skills within peas such as more aggressive in-crop harrowing in later years also contributed towards the reduction. A comparison of weed biomass between Reduced and High input systems indicates there is no evidence to date that chaff collection has reduced weed biomass. This suggests that if chaff collection has caused a reduction in the weed seed bank it has not been sufficient to reduce weed competition.

Interaction Between Precipitation Patterns and Management Decisions

Weed biomass like crop biomass was to a large degree dependent on the distribution of precipitation during the growing season. Not surprisingly June and July precipitation amounts appeared to have the greatest impact on pre-harvest weed biomass. Years with above normal July precipitation were classified as wet years and those with below normal precipitation in July as dry years. The years 1996, 1999 and 2000 were characterized with below normal June precipitation but above normal July precipitation. In contrast 1997 and 1998 had above normal June precipitation but below normal July precipitation (Table 1). In wet years July precipitation was on average 42% greater then the long term mean and in dry years was 68% less.

Within the Organic input system weed biomass declined in 1997 followed by a gradual increase until 2000 with only a slight dip in 1999 (Fig 3). As many of the tillage operations for weed control were concentrated near the time of seeding it was not surprising to see the close relationship between weed biomass in the Organic input system and combined June-July precipitation amounts. These results suggest that weed establishment was dependant on June precipitation while weeds added to their growth in response to late June or July precipitation. Lower then expected weed biomass in 1999 despite high June-July precipitation underlines the importance of precipitation patterns in determining the effectiveness of tillage operations. In 1999 moist conditions encouraged weed growth prior to seeding while dry conditions delayed weed growth after seeding. This greatly enhanced the effectiveness of pre-seed tillage and post-seed harrow operations and reduced weed biomass.

Within the Reduced input system the same general trends in weed biomass were observed over time with weed biomass gradually increasing after 1997 (Fig 3). In contrast to the Organic input system however weed biomass variability among years was more closely related to July precipitation. In-crop herbicides, generally applied near the middle of June, served to eliminate any weed growth in the Reduced input system up to that time. Weeds emerging after herbicide application would have reached their growth phase in late June or early July and as a result responded to July precipitation. Not surprisingly the same relationship was observed in the High input system where in-crop herbicides were also applied (Fig 3). Only in 1996 and to a lesser extent in 1999 were low levels of weed biomass measured despite above normal July precipitation. High crop biomass yields in those years suggest that crop competition may have kept weed biomass levels in check. In the Reduced and High input system in-crop herbicides minimized the risk associated with precipitation patterns. Herbicides were effective in negating weed growth encouraged by June rains and limited weed response to late June and July precipitation by delaying weed growth and allowing the crop to become more competitive. Weed growth in the High and Reduced input system however continued to be greater in years with greater July precipitation amounts.

When weed biomass was compared among levels of inputs and across years weed biomass in the Organic input system was generally greater and more variable then in the Reduced or High input system (Fig 4). Between 1996 and 1998 the Organic input system produced more weed biomass then either the Reduced or High input system (P=0.05). After 1997 weed biomass production within the Organic input system tended to level off while weed biomass in the Reduced and High input system gradually increased. This resulted in a gradual reduction in weed biomass differences between input levels. In 1999 Organic weed biomass levels were comparable to weed biomass levels in the Reduced input system and in 2000 comparable to the High input system.

A comparison of weed biomass production between 1996 and 2000 for each of the three cropping diversities showed generally greater weed biomass production in the DAG diversity. Greater weed biomass within DAG could be attributed to greater weed biomass growth in the ORG-DAG system. All three cropping diversities however showed similar weed biomass trends over time (Fig 3).

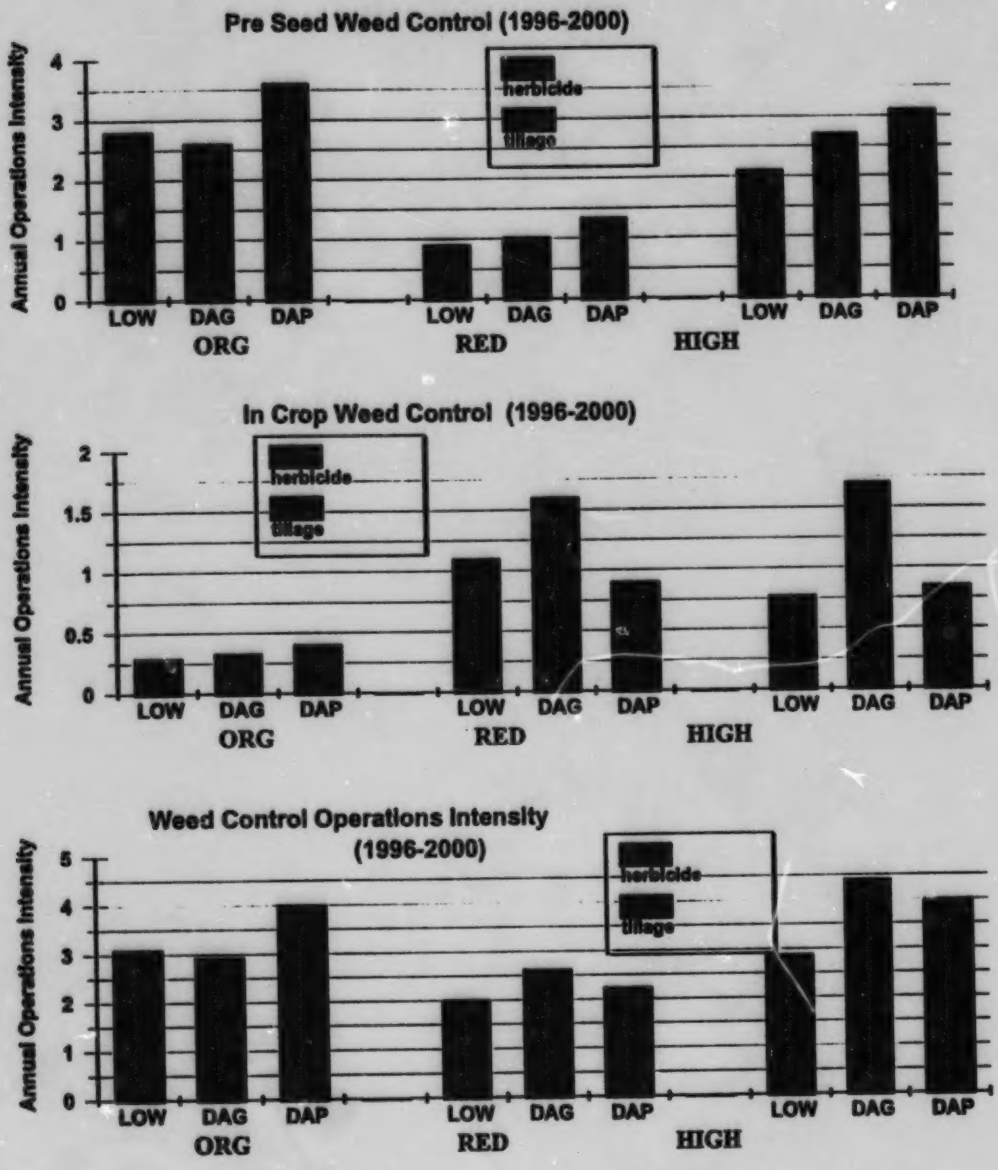
Weed Trends in the Organic Input System

Large fluctuations in weed biomass production among years within the Organic input system makes determination of weed biomass trends on the basis of weed type an uncertain exercise. Despite a gradual decline in volunteer and grassy weeds between 1996 and 2000 and an increase in broadleaf weeds, standard errors of the means and statistical evaluation of linear slopes suggest the trends are not significant (Fig. 4). Given the dependance of weed biomass production on precipitation additional years of data will be required before broadleaf, grassy, and volunteer weed trends or trend differences between diversities can be established with any confidence.

Table 1. Precipitation at Scott between 1996 and 2000.

Month	1996	1997	1998	1999	2000	Long Term
May	32	27	5	46	6	34
June	41	60	105	44	33	67
July	106	26	16	78	94	66
August	43	26	14	54	52	44
Total	222	139	140	222	185	209
	wet	dry	dry	wet	wet	

Figure 1. Tillage and herbicide weed control operation intensities between 1996 and 2000 for three levels of inputs and three levels of cropping diversity.



Pre Seed Weed Control (1996-2000)

In Crop Weed Control (1996-2000)

Weed Control Operations Intensity (1996-2000)

Figure 2. Average annual weed biomass yield for 3 input levels and 3 cropping diversities between 1996 and 2000 and relative contribution by crop. The LSD0.05 value allows comparison of average annual weed biomass between any two of the nine systems.

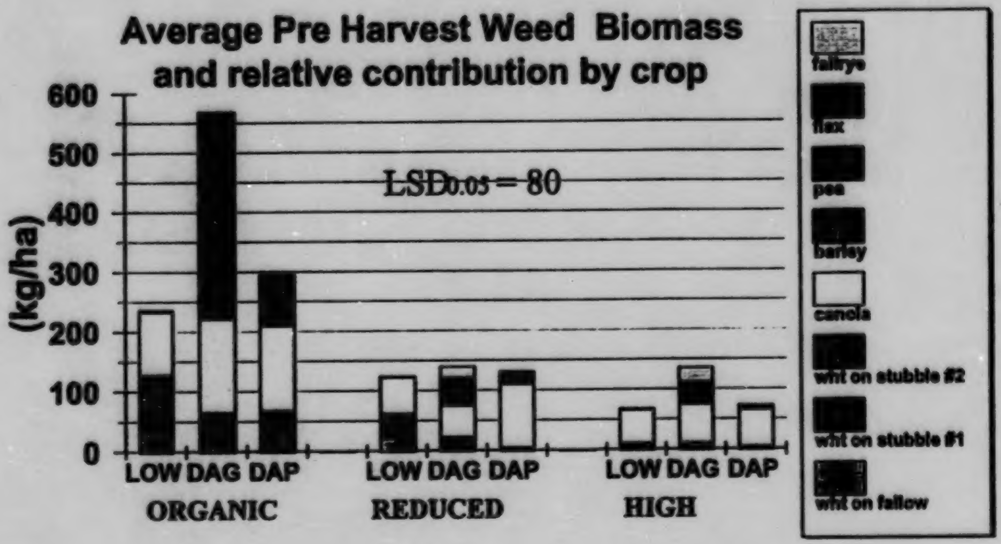
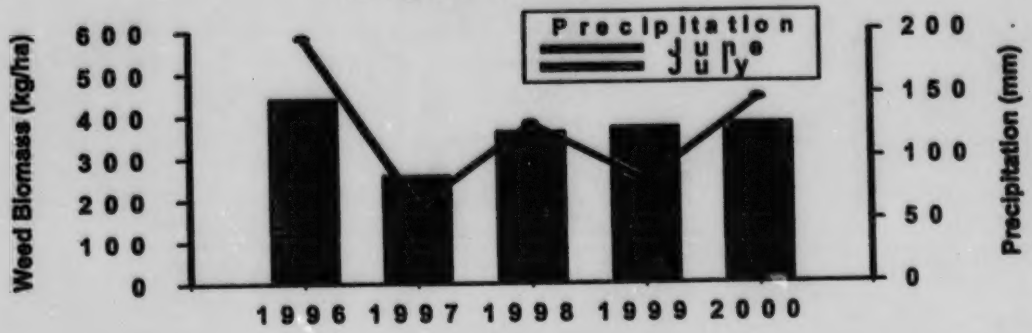
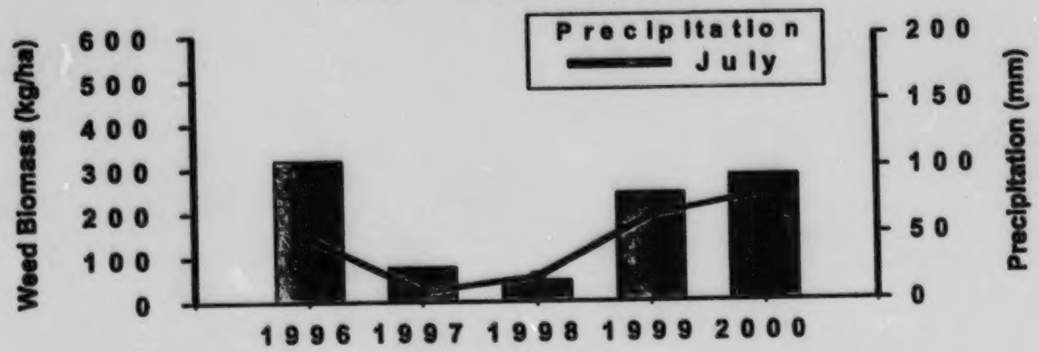


Figure 3. Weed biomass for 3 levels of inputs for years between 1996 and 2000 along with June and/or July precipitation.

Organic Inputs



Reduced Inputs



HIGH Inputs

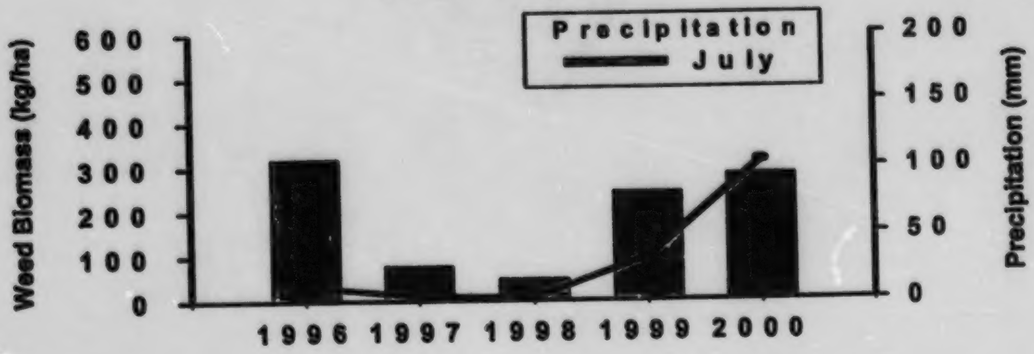
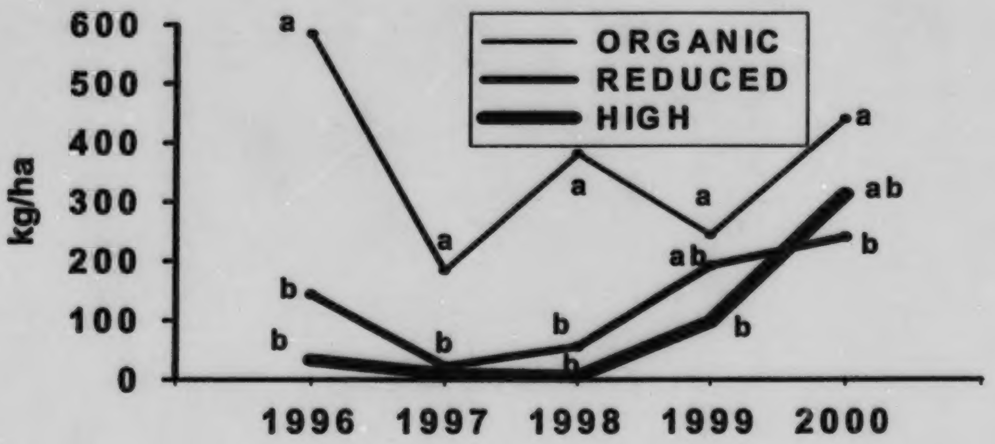
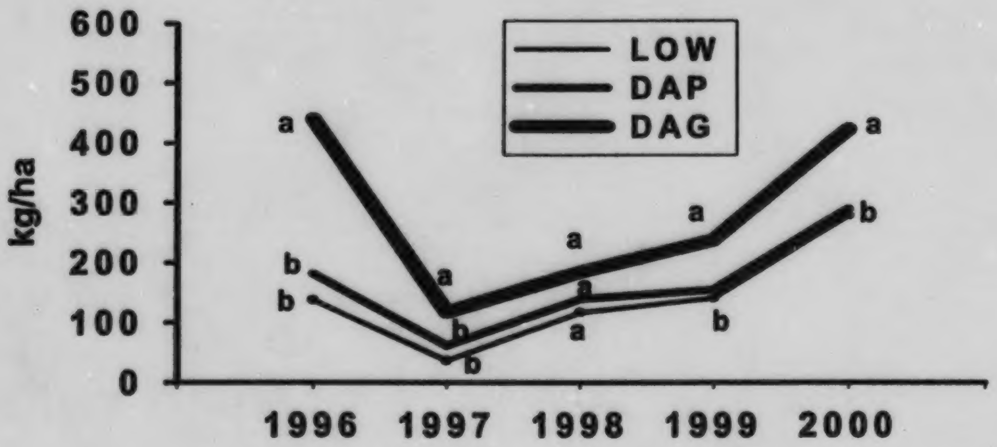


Figure 4. Weed biomass comparisons for individual years between 1996 and 2000 for 3 levels of inputs and 3 levels of cropping diversities. Weed biomass values within years followed by the same letter are not different



(P=0.05).



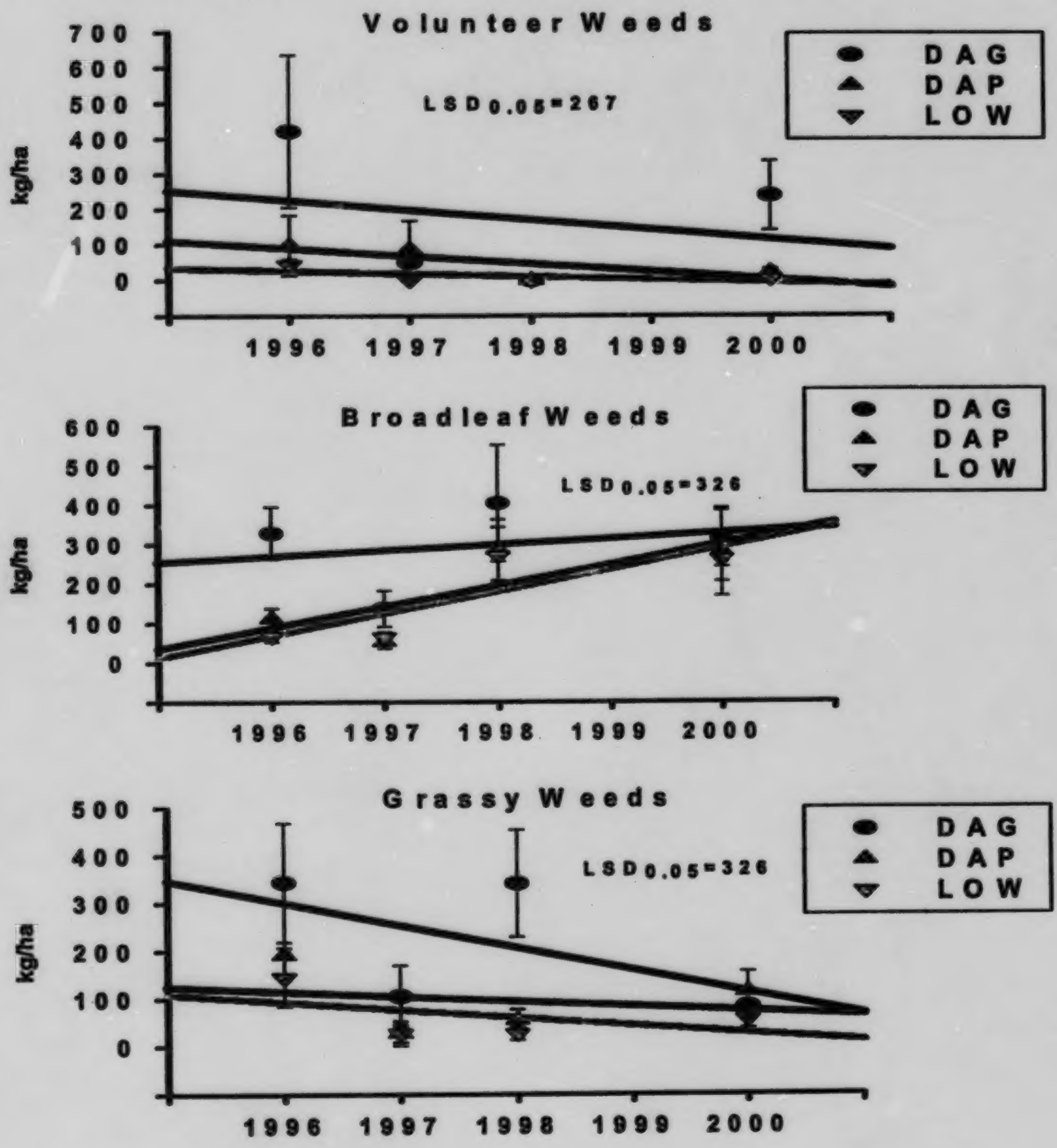


Figure 5. Volunteer, broadleaf and grassy weed biomass for 3 cropping diversities between 1996 and 2000. Lsd0.05 values allow comparisons between any 2 data points on the graph while error bars represent the standard error of the mean for each plotted value.

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Monitoring Soil Quality Attributes of the Alternative Crop Production Systems Study

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Rationale

Assessing the sustainability of a cropping system is a considerable challenge. The factors involved are complex and diverse. Soil quality is a critical factors to be considered, however, soil quality is in itself a complex and diverse concept that has proven difficult to define. Although an unequivocal definition of soil quality not been articulated, there is general agreement that it encompasses three broad issues: 1) plant and biological productivity, 2) environmental quality, and, 3) human and animal health. The quality of a soil, as it pertains to each of these issues, depends upon numerous physical, chemical, biological and biochemical properties. Clearly a suite of measures is required to establish the status of a soil's quality as no single measure could inform us about all these various aspects. The combination of attributes selected must be quantifiable, be sensitive to short-term changes and should reflect major soil processes (Trasar-Cepeda et al. 1998). If these indicators are then monitored over time, a reasonable indication of the trajectory of soil quality should emerge. One possible suite of analysis has been successfully utilized by workers at SPARC to distinguish soil quality changes resulting from crop rotations, changes in tillage intensity and/or cropping frequency. We will employ this same approach to determine how input intensity and crop diversity affect physical, biological and biochemical aspects of soil quality.

Methods

Soil quality attributes (Table 1) are to be compared on a cropping systems basis, therefore soil samples were collected from one phase (wheat stubble) of each rotation. Phases selected for sampling are shown in bold in the following treatment list .

Organic input level

1. lentil-GM* – wheat** – wheat – lentil-GM – canola – wheat
2. lentil-GM – wheat – peas – barley (clover underseed)– clover-GM – canola
3. canola – wheat– barley - oats - forage - forage

Low and high input levels

1. lentil-GM – wheat – wheat – fallow – canola – wheat
2. canola – fall rye – peas – barley – flax - wheat
3. canola – wheat – barley – oats – forage - forage

* GM = green manure

Six soil samples were collected from the 0-7.5 and 7.5-15 cm depth. The samples were composited, sieved (2 mm) and split into two halves. One-half of each sample was stored in field moist condition at 4 °C until determinations of microbial biomass C (MBC), microbial biomass N (MBN), carbon mineralization (Cmin) enzyme activities, and water-soluble organic-carbon could be conducted. The other half of each soil sample was air dried and stored until the balance of the determinations (see Table 1) could be conducted. Additional deep coring (0-240 cm) to assess NO_3^- leaching was conducted on the same plots. A single core, split into 9 increments (0-15, 15-30, 30-60, 60-90, 90-120, 120-150, 150-180, 180-210, 210-240 cm) was collected from each plot. Soil water, NO_3^- and phosphate were determined on each depth increment.

Table 1. Listing of specific soil quality analysis to be conducted, and methodologies employed.

Determination	Procedure
Bulk density	calculated from coring tube volume and soil mass
pH	saturated paste (H_2O)
Light fraction C & N	densiometric separation; C & N by dry combustion
Total organic C & N	dry combustion
Respiration	30 d incubation at field capacity and 22 °C
Water-soluble organic-C	water extraction; C determination by persulfate oxidation
Microbial biomass C & N	chloroform fumigation - incubation
enzyme activity (Dehydrogenase; ß-glucosidase; Glutaminase)	2,3,5-triphenyltetrazolium chloride conversion; p-nitrophenyl-ß-D-glucoside hydroslysis; and L-glutamine hydrolysis
NO_3^- leaching	KCl extraction of deep cores; colorimetric determination
specific respiratory activity	calculated from other measures

Results and Discussion

Several of the determinations have not yet been completed at the time of this writing. Interpretion of results will be speculative without reference to other indicators in the suite of measurements. Consequently, only a few preliminary remarks will be offered at this time. Light fraction carbon (LFC) levels tended to be highest on the Reduced Input treatments and lowest on the High Input treatments (Figure 1). No clear trends were apparent between cropping diversity levels. The lower LFC levels on the High Input treatments is most likely related to the high tillage intensity on these treatments compared to the low input treatments. This is consistent with previous studies that have shown decreasing levels of organic carbon (SOC) with increasing tillage intensity levels. These studies have also shown LFC to be a sensitive indicator of SOC changes. Interestingly, the Organic regime appears to partially mitigate the impact of tillage. Light fraction carbon levels were intermediate on the Organic treatments even though tillage intensity is actually highest on these treatments. Statistical analysis has not been conducted on mineralized nitrogen (cumulative over 16 weeks), but the general trends (Figure 2) are quite consistent with LFC. Trends in wind-erodible and water-stable aggregate percentages were not consistent (data not shown). Trends developing in these parameters may have been obscured by the tillage pass that all plots received just prior to soil sampling.

Figure 1. Light fraction carbon

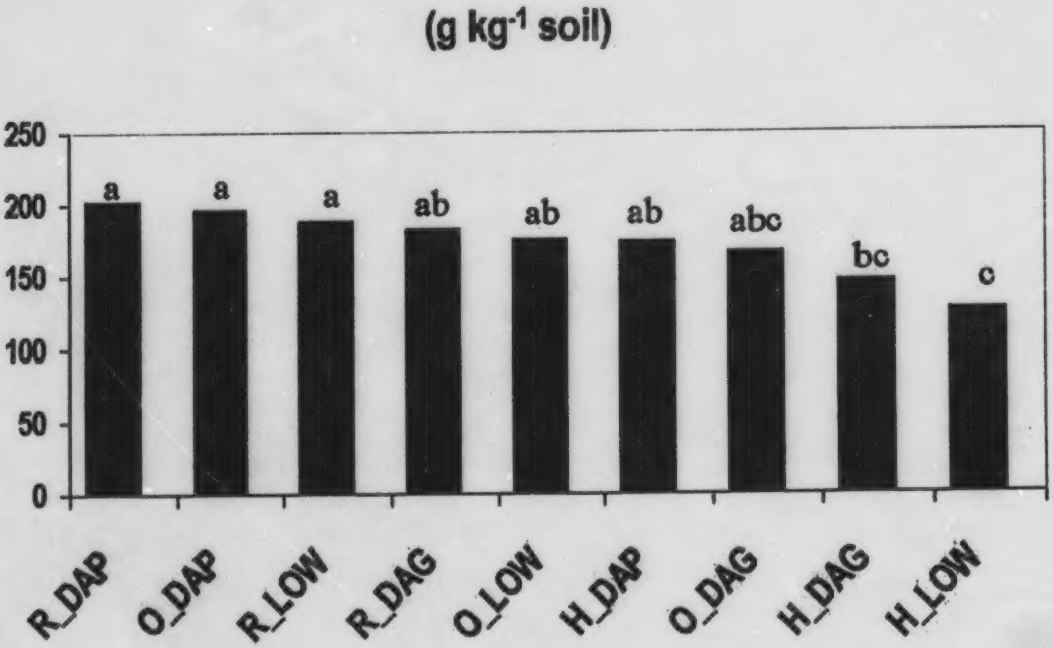
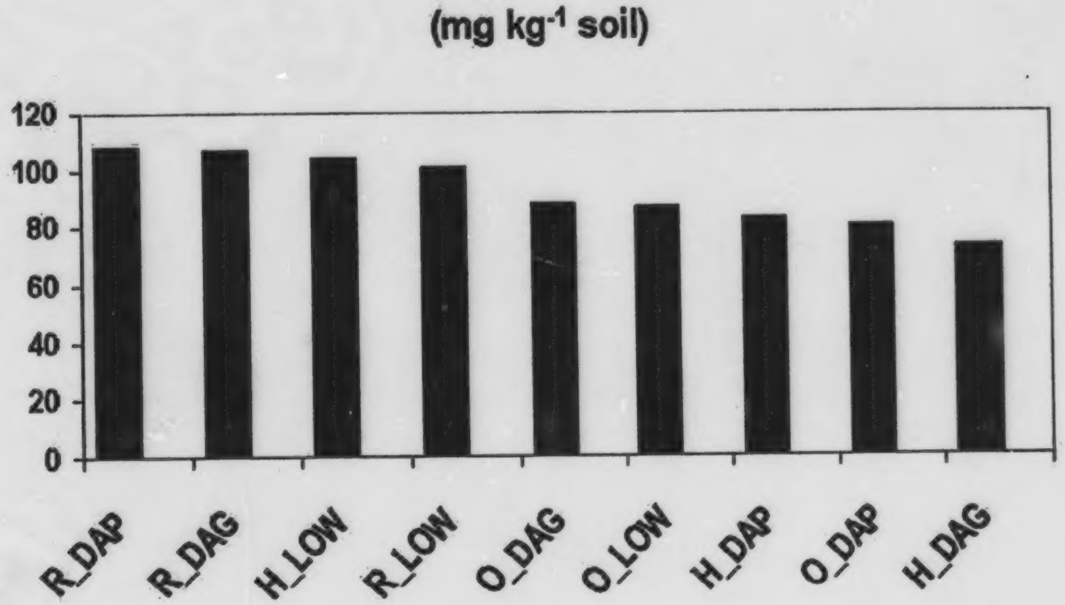


Figure 2. Mineralizable N (cumulative 16 weeks)



Reference

Trasar-Cepeda, C., Leiros, C., Gil-Sotres, F., and Soane, S. 1998. Towards a biochemical quality index for soils: an expression relating several biological and biochemical properties. Biol. Fertil. Soil 26:100-106.

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Soil Microbial Activity After the First Rotation Cycle of the Alternative Cropping System Study at Scott, SK

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Rationale

Any real assessment of soil quality must include and emphasize biological soil properties because they:

- relate better to ecosystem functions (C & N cycling),
- are more sensitive to management and climate effects,
- are better early indicators of changes in soil quality than routinely measured physical and chemical properties.

This component of the study was done to gain a better understanding of the effect of cropping diversity and systems on soil biological quality.

Methods

Plots in the wheat phase after a non-cereal crop were chosen for sampling at the end of the first cycle of rotations from each crop diversity by input combination. Soil samples were collected at two depths (0-7.5 cm and 7.5-15 cm) at six locations in each plot using a modified Dutch bulb planter on October 18, 2000. Subsamples for each soil depth from each plot were bulked. Samples were shipped to the lab, mixed, sieved and stored field-moist at 0 C until analysis.

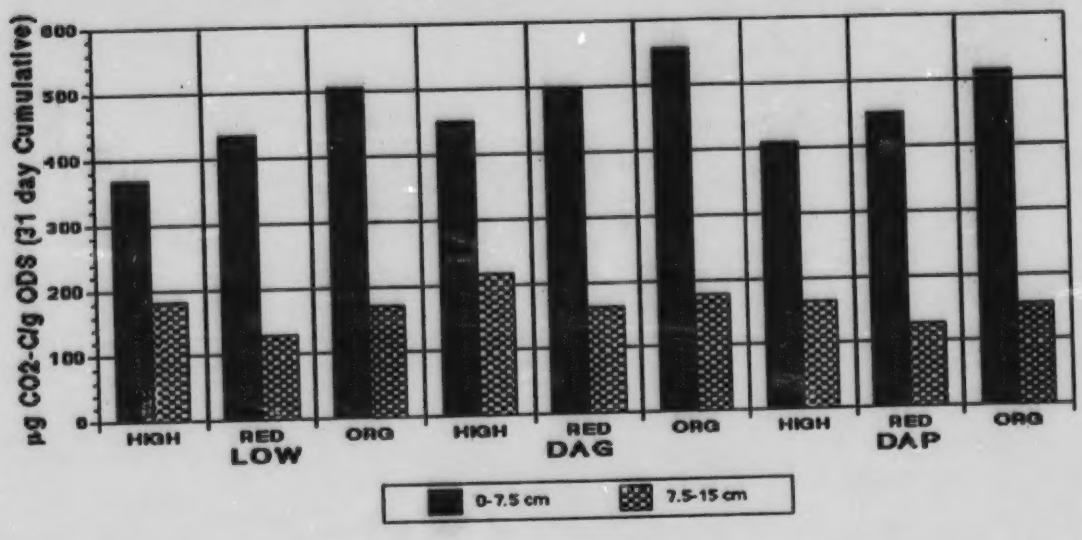
Soil microbial respiration (C-mineralization) was determined according to the method of Bartha and Pramer (1965) during incubation at 21 C and accumulated for 31 days. Dehydrogenase enzyme activity was determined according to the method modified from Tabatabai (1982) and was measured by the conversion of 2, 3, 5-triphenyltetrazolium chloride (TTC) to triphenyl formazan (TPF) over a 24 h period. ß-glucosidase enzyme activity was determined using the method from Tabatabai (1982) and was measured by the hydrolysis of p-nitrophenyl-ß-D-glucoside which released p-nitrophenol that is measured after 1 h of incubation.

Data were analyzed by ANOVA using JMP (SAS, Gary, NC) and means comparisons determined by contrasts.

Results and Discussion

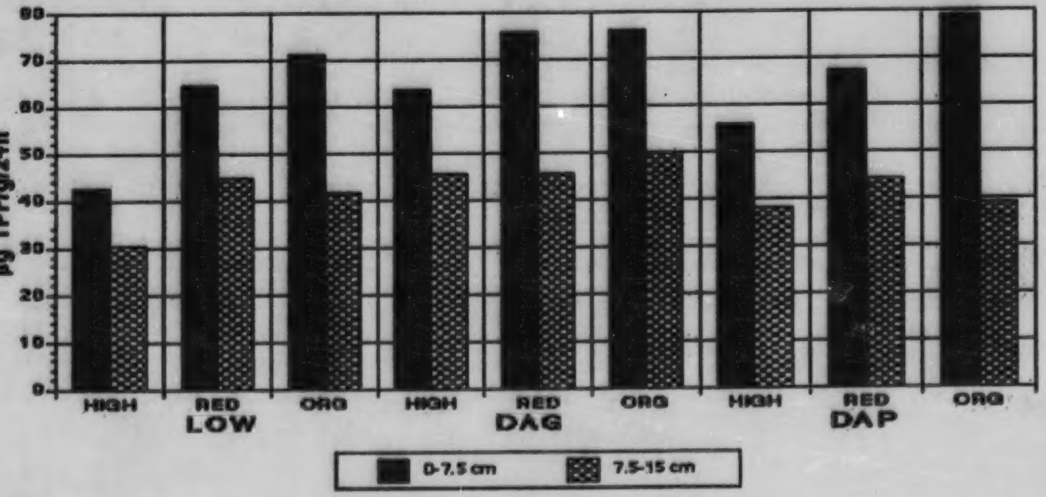
Soil respiration (carbon mineralization) was at least twice as high and often was a 3-fold increase at the 0 – 7.5 cm soil depth over the 7.5 – 15 cm depth (Figure 1). For C-mineralization in the top 7.5 cm of soil, overall CO2-evolution in ORG was significantly higher than at the other input levels with the trend being that HIGH input had consistently the lowest activity and RED was intermediate. DAG had higher levels of respiration than the other cropping diversities although this effect of diversity was not quite significant (data not shown). In the lower soil depth there were no trends evident and no treatments were significantly different from each other (Figure 1).

Figure 1. Effect of cropping and input system on cumulative soil respiration (31 days) after the first cycle of rotations of the ACS sampled in October 2000 at Scott, SK.



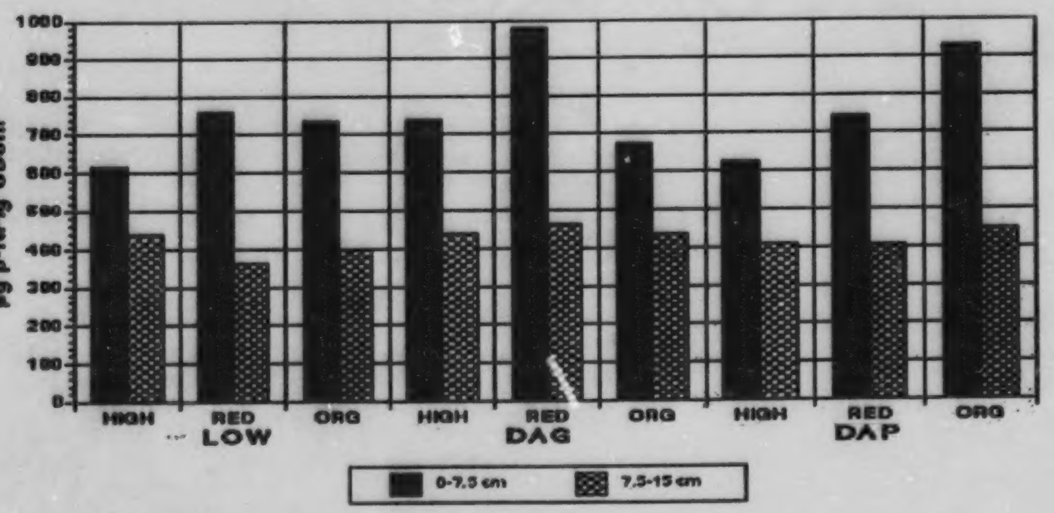
Dehydrogenase enzyme activity was also significantly higher near the soil surface as compared to the lower depth, however the increases were not as large as those found for C-mineralization. As noted for soil respiration, the HIGH input level also had consistent ly the lowest dehydrogenase enzyme activity for each crop diversity level but the relative increase in activity from RED to ORG varied with the least difference occurring in DAG for soil at the 0-7.5 cm depth (Figure 2). In the 7.5-15 cm soil depth there were again no significant differences between treatments and no trends were evident (Figure 2).

Figure 2. Effect of cropping and input system on dehydrogenase enzyme activity after the first cycle of rotations of the ACS sampled in October 2000 at Scott, SK.



Greatly increased levels of ß-glucosidase enzyme activity were evident in the top 7.5 cm of soil when compared to the lower depth (Figure 3). However, the trends found so consistently in the 0 – 7.5 cm depth with regard to the other two parameters measured were not evident for ß-glucosidase activity, especially in the DAG crop diversity (Figure 3).

Figure 3. Effect of cropping and input system on ß-glucosidase enzyme activity after the first cycle of rotations of the ACS sampled in October 2000 at Scott, SK.



The top 7.5 cm was found to be very similar to the depth of tillage or other soil disturbance as was observed during manual soil sampling. With most of the input system applications and tillage occurring in the top depth, it was not surprising that most differences in microbial activities were found here. Microbial activity in the top 7.5 cm of soil was definitely stimulated by organic production systems regardless of cropping diversity for most parameters measured. The increased microbial activities in the organic production systems were most likely the result of the inclusion of legume green manuring in these systems. For a Brown loam in southwest Saskatchewan, Biederbeck et al. (1995) reported that short-term legume growth and soil incorporation caused microbial populations to shift toward greater metabolic activity with increased respiration and enhanced enzyme activities. A recent study on a Palouse soil in eastern Washington also found that organic crop management resulted in a strong stimulation of various soil biological activities (Carpenter-Boggs et al. 2000). The trend for both C-mineralization and dehydrogenase enzyme activity was to find increased activity as inputs decreased within each crop diversity group (Figures 1 & 2). Both C-mineralization and dehydrogenase are direct measures of activity within the living microbial biomass in the soil as both activities take place primarily inside metabolically active microorganisms. However, ß-glucosidase is an extracellular enzyme and consequently its activity is partly due to molecules adsorbed by soil colloids and may not be as closely linked to living microbial biomass. This may have resulted in the lack of a consistent trend with this enzyme analogous to the trends observed for the other two activities in the 0 – 7.5 cm depth.

Further analyses are required for a more complete study of cropping systems effects on the soil microbiota and their impact on soil biological quality. Microbial biomass C, glutaminase enzyme activity, water soluble organic C and microbial functional diversity analyses have yet to be completed. Full discussion of the results is not possible until all analyses are completed and ratios and correlations can be calculated.

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Accumulation and Distribution of Nitrate-N and Extractable P in the Soil Profile under Various Alternative Cropping Systems

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Rationale

A field experiment was conducted on a Dark Brown loam soil at Scott, Saskatchewan from 1995 to 2000 to determine the influence of input level and cropping diversity on the accumulation and distribution of nitrate-N and extractable P in the soil. There were a total of 54 treatments including three input levels (organic - ORG, reduced - RED and high - HIGH) and three cropping diversities (monocrop - LOW, diversified annual grains - DAG, and diversified annual and perennial - DAP) with six year crop rotations/sequences. In each plot, the soil was sampled to 0-6, 6-12, 12-24 and 24-36 inches depths every year in fall after harvesting. In general, there were greater amounts of nitrate-N in 0-36" soil at HIGH input level, especially under LOW cropping diversity. The nitrate-N in various soil depths suggest some downward movement of nitrate-N in the soil profile when HIGH input was compared to ORG. In LOW cropping diversity, green manure or summerfallow usually had more nitrate-N in soil than the other treatments. In DAG and DAP cropping diversities, nitrate-N varied with crops (on average highest after wheat or canola in DAG and after hay followed closely by wheat in DAP. In some instances, ORG input level had greater nitrate-N than RED. This may be most likely due to lack of P in soil for optimum crop growth. HIGH or RED input levels tended to have more extractable P in the 0-6 and 6-12" soil depths than the ORG input level in many cases in all years. These was no consistent effect of cropping diversity on extractable P in soil.

Changes in nutrient accumulation and distribution in soil profile vary with rates, sources and duration of fertilizer applications, soil management practices, crop species, yield potential, rooting depth/volume/mass, soil type, climate, amount and placement of residues, etc. (Seyfried et al., 1991; Edwards et al, 1992; Brar et al., 1993; Guillard et al., 1995; Cowie, et al., 1996; Katupitiya et al., 1997; Vos et al., 1998 and Nikitishen et al., 1999). Under and over fertilization is uneconomical, but any fertilizer N applied in excess of crop needs has the potential for environmental damage through nitrate leaching and denitrification.

Crops with taproots can go deep into the soil and crops with fibrous roots can not reach deep sub-soil. Nutrients present in the sub-soil are used by taproot plants and become available at the surface after crop residues are returned to the soil. This can improve the economic productivity under low fertility conditions in the surface soil. Under high fertility conditions, this can improve the retention of nutrients and minimize environmental damage.

In the soil depth profile, the concentration of nitrate-N can be elevated by legumes in a rotation, green manure and summerfallow, etc. (Guillard et al, 1995 and Katupitiya et al., 1997). High rates of N fertilization and limited crop uptake of N during the growing season can result in excessive accumulation of nitrate-N in the soil (Guillard et al., 1995). Soil nitrate-N can be decreased with efficient cropping. The stratification of P in soil can occur under no-tillage cropping systems (Cowie et al., 1995 and Holanda et al., 1998).

The objective of this paper is to summarize the 6-year information to determine the influence of input level and cropping diversity on accumulation and distribution of nitrate-N and extractable P in the soil under various alternative cropping systems.

Methods

The field experiment was established in 1995 on a Dark Brown loam soil at Scott, Saskatchewan. The 54 treatments included three levels of inputs (organic, reduced and high) and three cropping diversities (monocrop, diversified annual grains and diversified annual with perennial) and six year crop rotations/sequences. In the organic (ORG) input level, the management was based on non-chemical means to mimic what an organic grower might do. Under reduced (RED) input, long-term management and reduced tillage were used to reduce non-renewable inputs while chemicals are used to supplement management practices. In the high (HIGH) input treatment, the inputs were based on pest thresholds and soil tests. Chemical inputs complimented conventional tillage practices. In the low (LOW) cropping diversity, the crop sequence was fallow-wheat-wheat-fallow-canola-wheat. The fallow was managed as green manure (GM) fallow under ORG, GM and chemical fallow under RED, and tillage fallow under HIGH input system. In the DAG cropping diversity, the six-year crop rotations were GM fallow-wheat-pea-barley-GM fallow-canola under ORG, canola-fall rye-pea-barley-flax-wheat under RED and HIGH input systems. For the DAP, there was a mixed rotation of annual grains and perennials including canola-barley-oat underseeded to brome/alfalfa-brome/alfalfa hay-brome/alfalfa hay. More details on treatments are given in a paper by Ulrich (2001).

After harvesting, each plot was soil sampled (2 cores per plot) to 0-6, 6-12, 12-24 and 24-36 inches depths in the fall of every year. The samples were air dried, ground to pass a 2-mm sieve and analyzed for nitrate-N and extractable P.

Results and Discussion

Nitrate-N in soil

The amount of nitrate-N in soil varied with input level. On average, the amount of nitrate-N in the 0-36" soil layer was usually highest with HIGH input level and lowest with ORG input level (Table 1). In 1998, 1999 and 2000, HIGH input level had higher nitrate-N in all the soil layers, especially when compared to ORG input level. This suggests that some downward movement of nitrate-N is occurring in soil profile under HIGH input compared to ORG input. Because of the reduced input to soil system, organic agriculture, if managed properly, may considerably decrease risks of nitrate leaching in soil (Kolbe et al., 1999).
LOW cropping diversity had the highest nitrate-N in soil in all years, particularly when compared to DAP (Table 2). In 1998, 1999 and 2000, the nitrate-N was greatest with LOW and lowest with DAP in all the 0-6" 6-12" 12-24"and 24-36" layers.

The amounts of nitrate-N in the 0-36" layer were greater under HIGH input level in most cases, especially under LOW diversity (Table 3). The combination of HIGH input level and LOW diversity gave the highest amount of nitrate-N in soil in all cases. This may be associated with greater use of N fertilizer under HIGH input level and more release of mineral N under green manure/summerfallow in LOW cropping diversity.

Table 1. Distribution of nitrate-N in the soil profile in relation to input levels in 1995 to 2000 at Scott, Saskatchewan.

		Nitrate-N (lbs/ac) in soil layers (inches)				
Year	Input level	0-6	6-12	12-24	24-36	0-36
1995	ORG	10.0	7.3	8.3	13.3	38.9
	RED	16.0	9.7	10.3	15.3	51.3
	HIGH	22.3	11.7	9.0	13.3	56.3
1996	ORG	17.0	7.0	6.3	10.7	41.0
	RED	13.3	6.3	9.3	12.3	41.2
	HIGH	17.3	10.0	8.0	11.0	46.3
1997	ORG	15.3	12.3	9.7	13.3	50.6
	RED	20.3	13.0	9.0	16.0	58.3
	HIGH	29.0	22.7	13.7	15.7	81.1
1998	ORG	16.7	8.3	9.0	12.7	46.7
	RED	21.0	9.3	13.3	17.3	60.9
	HIGH	30.0	16.0	16.0	18.0	80.0
1999	ORG	9.3	5.3	6.7	8.7	30.0
	RED	9.3	5.7	7.7	9.7	32.4
	HIGH	13.0	10.0	13.3	15.3	51.6
2000	ORG	16.3	9.0	9.0	12.3	46.6
	RED	13.0	7.3	9.3	14.3	43.9
	HIGH	15.7	10.3	14.3	16.0	56.3

In LOW cropping diversity, green manure/summerfallow had the highest mean nitrate-N in soil (70-79 lb nitrate-N /ac for GM/F vs 48-53 lb nitrate-N/ac for other phases of wheat or canola (Table 4). The frequency of occurrence was also highest with this crop phase over the 6-yr period.

The mean amounts of nitrate-N in the 0-36" soil layer were greater in 1997 and 1998 than the other years. This could be due to low rainfall in the growing season which may have resulted in poor crop growth and uptake of N by the crop, leaving greater residual nitrate-N in soil in 1997 and 1998 compared to other years.

In almost all crop phases, the nitrate-N in soil was highest with HIGH input level. In some instances, ORG input level had greater nitrate-N than RED input level. This could be due to lack of P in soil in the ORG system for optimum plant growth, but this needs further verification.

Table 2. Distribution of nitrate-N in the soil profile in relation to cropping diversity in 1995 to 2000 at Scott, Saskatchewan.

		Nitrate-N (lbs/ac) in soil layers (inches)				
Year	Diversity level	0-6	6-12	12-24	24-36	0-36
1995	LOW	19.7	12.3	11.0	15.0	58.0
	DAG	13.7	9.7	9.0	14.7	47.1
	DAP	15.0	8.7	7.0	12.3	43.0
1996	LOW	18.3	10.0	9.0	12.7	50.0
	DAG	13.0	6.7	7.0	11.7	38.4
	DAP	16.3	6.7	7.7	9.7	40.4
1997	LOW	23.3	18.7	12.0	16.0	70.0
	DAG	22.0	15.3	9.3	13.3	59.6
	DAP	19.3	14.0	11.0	15.7	60.0
1998	LOW	26.0	13.3	16.3	17.7	73.3
	DAG	20.0	10.0	12.7	17.7	60.4
	DAP	21.7	10.3	9.3	12.3	53.6
1999	LOW	10.7	8.0	12.3	14.7	45.7
	DAG	9.3	6.3	8.7	10.3	34.6
	DAP	11.7	6.7	6.7	8.7	34.8
2000	LOW	18.7	11.3	14.0	16.0	60.0
	DAG	14.7	8.3	10.7	15.7	49.4
	DAP	11.7	7.0	8.0	11.0	37.7

In the DAG cropping diversity, nitrate-N in 0-36" soil layer varied with the crop in different years and there was no consistent trend of nitrate-N in soil with input level (Table 5). Overall, the amount of nitrate-N tended to be highest with wheat and canola (55 lb nitrate-N/ac) and lowest with barley and peas (43 lb nitrate-N/ac). In several instances, nitrate-N was highest with ORG input level. This may be associated with yield in relation to climatic conditions and/or lack of other nutrients in soil, such as P. Like LOW cropping diversity, DAG also had higher amounts of nitrate-N in soil in 1997 and 1998 than the other years.

The amount of nitrate-N in soil in DAP also varied with crop from year to year, without any consistent trend (Table 6). For hay, nitrate-N tended to be higher than annual grains in several cases. This is contrary to the earlier findings, as forages grown for hay are expected to leave less residual mineral N in soil. This may be due to the fact that forage crops did not establish very well, which probably resulted in poor uptake of fertilizer N. Also, the forage was a mixture of brome and alfalfa, and inclusion of alfalfa probably also reduced the N requirement for hay production.

Like other cropping diversities, the amounts of nitrate-N in soil were much greater in 1997 and 1998 than the other years.

Table 3. Influence of cropping diversity on nitrate-N in soil (0-36") under three input levels at Scott, Saskatchewan in 1995 to 2000.

		Nitrate-N (lbs/ac) in soil		
Year	Input level	LOW	DAG	DAP
1995	ORG	49	35	32
	RED	55	49	51
	HIGH	69	52	48
1996	ORG	43	44	35
	RED	44	35	46
	HIGH	64	35	40
1997	ORG	53	48	49
	RED	59	59	57
	HIGH	97	73	71
1998	ORG	50	50	40
	RED	71	65	48
	HIGH	100	66	74
1999	ORG	27	30	33
	RED	36	34	28
	HIGH	77	39	40
2000	ORG	48	61	32
	RED	48	47	37
	HIGH	84	41	45

Table 4. Influence of crop phase in LOW cropping diversity on nitrate-N in soil (0-36") under three input levels in 1995 to 2000 at Scott, Saskatchewan.

		Nitrate-N (lbs/ac) in soil					
Year	Input level	GM/F1	Wheat 1	Wheat 2	GM/F2	Canola	Wheat 3
1995	ORG	66	22	50	80	32	45
	RED	78	37	62	59	40	58
	HIGH	90	61	53	75	74	64
	MEAN	78	43	55	52	49	55
1996	ORG	80	47	24	50	32	28
	RED	72	30	52	74	15	18
	HIGH	105	41	70	110	19	39
	MEAN	85	39	49	78	22	28
1997	ORG	35	67	64	44	68	41
	RED	35	53	49	104	55	60
	HIGH	81	95	100	103	156	47
	MEAN	50	72	71	84	93	49
1998	ORG	60	47	47	50	49	53
	RED	75	54	109	99	35	52
	HIGH	105	67	76	100	96	154
	MEAN	80	56	77	83	60	86
1999	ORG	41	17	20	38	25	20
	RED	56	20	17	17	28	19
	HIGH	203	29	39	107	33	53
	MEAN	100	22	25	54	29	31
2000	ORG	74	34	44	74	29	32
	RED	70	44	36	53	44	39
	HIGH	105	181	36	75	61	48
	MEAN	83	86	39	67	45	40

Table 5. Influence of crop phase in DAG cropping diversity on nitrate-N in soil (0-36") under three input levels in 1995 to 2000 at Scott, Saskatchewan.

Year	Input level	Nitrate-N (lbs/ac) in soil					
		Canola	Fall Rye	Peas	Barley	Flax	Wheat
1995	ORG	28	25	38	34	36	48
	RED	24	43	48	54	50	73
	HIGH	51	28	33	61	67	74
	MEAN	34	32	40	50	51	65
1996	ORG	62	32	24	42	57	46
	RED	27	38	50	31	37	25
	HIGH	35	39	43	29	33	31
	MEAN	41	36	39	34	42	34
1997	ORG	42	55	43	51	37	59
	RED	66	60	51	61	60	57
	HIGH	80	87	67	69	71	66
	MEAN	63	67	54	60	56	61
1998	ORG	63	39	51	56	50	43
	RED	83	57	49	52	95	94
	HIGH	90	74	41	57	58	78
	MEAN	79	57	47	55	68	72
1999	ORG	41	22	37	18	34	27
	RED	36	24	33	18	36	56
	HIGH	32	73	41	31	38	23
	MEAN	36	40	37	22	36	35
2000	ORG	108	45	48	27	61	76
	RED	92	34	27	47	36	48
	HIGH	33	46	43	32	26	66
	MEAN	78	42	39	34	41	63

Table 6. Influence of crop phase in DAP cropping diversity on nitrate-N in soil (0-36") under three input levels in 1995 to 2000 at Scott, Saskatchewan.

		Nitrate-N (lbs/ac) in soil					
Year	Input level	Canola	Wheat	Barley	Oats(br/alf)	Hay 1	Hay 2
1995	ORG	22	25	26	23	34	63
	RED	52	61	48	49	41	55
	HIGH	56	64	42	25	29	70
	MEAN	43	50	39	32	35	63
1996	ORG	36	30	26	21	48	51
	RED	58	30	37	33	52	65
	HIGH	29	42	34	32	51	51
	MEAN	41	34	32	29	50	56
1997	ORG	34	72	42	66	35	48
	RED	37	49	52	58	86	62
	HIGH	98	74	103	54	54	45
	MEAN	56	65	66	59	58	52
1998	ORG	40	41	37	37	49	37
	RED	49	39	63	58	49	33
	HIGH	73	125	35	67	38	104
	MEAN	54	68	45	54	45	58
1999	ORG	22	17	19	22	46	72
	RED	29	21	18	18	57	25
	HIGH	25	32	46	28	64	46
	MEAN	26	23	28	23	56	48
2000	ORG	33	25	28	26	45	36
	RED	40	57	32	22	30	40
	HIGH	44	79	41	31	33	41
	MEAN	39	54	34	26	36	39

Extractable P

The amount of extractable P in the 0-36" soil layer tended to be greater at RED or HIGH input levels than at ORG input levels in all years, especially under LOW diversity (Table 7). This tendency of greater extractable P at RED or HIGH than the ORG input levels was in both the 0-6" and 6-12" layers (Table 8). There was no consistent effect of cropping diversity on extractable P in soil.

Table 7. Influence of cropping diversity on extractable P in soil (0-36") under three input levels in 1995 to 2000 at Scott, Saskatchewan.

		Extractable P (lbs/ac) in soil		
Year	Input level	LOW	DAG	DAP
1995	ORG	15	17	17
	RED	21	17	19
	HIGH	20	18	17
1996	ORG	19	19	18
	RED	23	22	22
	HIGH	22	19	23
1997	ORG	17	18	18
	RED	21	17	18
	HIGH	22	20	18
1998	ORG	18	18	19
	RED	21	20	23
	HIGH	20	21	21
1999	ORG	17	17	16
	RED	20	18	19
	HIGH	18	17	19
2000	ORG	13	13	14
	RED	16	15	18
	HIGH	15	19	16

Extractable P was low in the surface soil layers and markedly low in the sub-soil layers. This indicates that at this site there may be little potential for bringing P from sub-soil to the surface soil by using taproot crops. This also suggests that if surface and sub-soil are low in available P or some other nutrients, it may not be possible to sustain high crop yields under organic farming systems without using external nutrient sources (Adetunji, 1994).

Table 8. Distribution of extractable P in soil profile in relation to input levels in 1995 to 2000 at Scott, Saskatchewan.

Year	Input level	Extractable P (lbs/ac) in soil layers (inches)				
		0-6	6-12	12-24	24-36	0-36
1995	ORG	7.7	6.3	2.0	0.7	16.7
	RED	8.7	7.7	1.7	1.0	19.1
	HIGH	8.0	7.0	1.7	1.0	17.7
1996	ORG	9.0	7.3	1.7	0.7	18.7
	RED	10.3	8.0	2.7	1.7	22.7
	HIGH	10.7	8.0	2.0	0.7	21.4
1997	ORG	7.3	6.3	2.7	1.0	17.3
	RED	9.0	6.3	2.7	1.0	19.0
	HIGH	8.3	7.7	2.7	1.3	20.0
1998	ORG	8.0	6.7	2.3	1.3	18.3
	RED	10.0	7.0	3.3	1.0	21.3
	HIGH	9.7	7.3	3.0	1.0	21.0
1999	ORG	6.0	5.7	3.0	2.0	16.7
	RED	8.0	7.0	2.7	2.0	19.7
	HIGH	7.3	7.3	2.0	2.0	18.6
2000	ORG	6.0	5.0	1.3	0.0	12.3
	RED	8.3	5.3	1.7	1.3	16.6
	HIGH	8.0	6.0	1.7	1.0	16.7

Future soil sampling/analyses should include:

Soil properties, concentration and availability of other nutrients are also affected by long-term soil, fertilizer and crop management practices. Therefore, the following suggestions are made on future sampling and analyses of soil and plant samples:

- Sample soil also for 0-3" and 3-6" depths at the end of each 6-year rotation cycle (if not possible every year).
- Include 36-48" depth for soil sampling in the second 6-year rotation cycle.
- Include 48-60" depth for soil sampling in the third 6-year rotation cycle.
- Include soil analyses on NH4-N, K, and SO4-S, and if possible also include soil and plant analyses on Ca, Mg,, Zn, Cu, B, Mn, Fe, Cl, etc.
- Conduct a field experiment to determine the feasibility of rock phosphate fertilizers to correct P deficiency in crops.

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Alternative Cropping Systems

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Colonization of Non-Legumes by Rhizobia

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Rationale

The beneficial effects of legumes (grain, forage or green manure) in crop rotations have been recognized for decades. The benefits include breaking weed and disease cycles, improved fertility and quality of soil (Wright 1990; Campbell et al. 1992; Green and Biederbeck 1995; Biederbeck et al. 1998), reduced soil nitrogen losses (Drinkwater et al. 1998) and increased soil biological activity (Lupwayi et al. 1998; Biederbeck et al. 1999). Recently, it has been proposed that some of the benefit from legume inclusion in rotations may be due to rhizobial/non-legume associations in the rhizosphere, on the rhizoplane and in the root interior (Yanni et al. 1997; Höflich 1998; Biederbeck et al. 2000a; Lupwayi et al. 2000, Hanson and Biederbeck 2001). The rhizobia associated with root interiors are referred to as endophytic rhizobia and have generated the greatest interest.

Endophytes are described as bacteria that can be isolated from surface-disinfected plant tissue and that do not visibly harm the plant. Yanni et al. (1997) found berseem clover rhizobia isolated from rice roots promoted rice production including yield. Recent work has shown that maize, spring wheat, barley and canola can also harbour endophytic rhizobia when grown in rotation with legumes (Höflich 1998; Biederbeck et al. 2000a; Lupwayi et al. 2000). The legumes in these rotations can also vary from pulses like lentils, peas and beans to forage legumes like red clover and berseem clover.

Endophytic rhizobia have been found to affect many different benefits in non-legume crops that include:

- increased rate of seedling emergence,
- improved root architecture,
- increased height and dry matter,
- increased root and leaf areas,
- increased grain and straw yields, and
- increased nitrogen content of straw.

The plant growth promoting activities that rhizobial endophytes possess include:

- phosphate solubilization,
- improved nitrogen use,
- increased uptake of other macro- and micronutrients,
- production of phytohormones,
- production of siderophores and HCN, and
- antagonism of plant pathogenic fungi.

The existence of the long-term lentil-wheat rotation in the 'Old' rotations study at SPARC in Swift Current made it possible for Hanson and Biederbeck to evaluate endophytic rhizobia. The million- to many thousand-fold greater populations of rhizobia near and inside the roots of wheat after lentil, as compared to monoculture wheat, attest to the benefits of legumes and suggest that colonization of cereal roots by rhizobia intensifies with frequency of legumes in the rotation (Hanson and Biederbeck 2001). This was also reflected in findings by Lupwayi and Rice (2000) where barley and canola, when grown in short rotations with peas, have endophytic rhizobia and the associated beneficial effects, however, the population levels of endophytes were much lower than those found in the long-term lentil-wheat rotation at SPARC.

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Spatial Variability of Weed Populations and Soil Fauna

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Rationale

In 1994, the site characterization year, the project area was uniformly cropped to barley and treated with pesticides. Weed populations were assessed in each plot in June, prior to in-crop herbicide application, and in August, to assess the residual populations (Thomas et al. 1999). Despite the fact that no treatments had been applied, both of these assessments varied significantly among treatments. In the fall of 1994, the high and organic input plots were cultivated. The weed seedbank was sampled in April 1995 prior to the initiation of any of the spring treatments (Derksen 1999). Soil fauna were sampled in May 1995, also prior to any spring treatments (Braun et al. 1999). Spatial variability was observed in the spring 1995 assessments beyond that which could be expected based on the presence of fall cultivation.

Also during the site characterization year, spatial distribution of the soil chemical, soil physical and topographic factors were determined for the project area. Although the project area was chosen to be relatively uniform, variation across the site was present in all of these factors (Moulin and Selles 1999, Selles et al. 1999).

In the years prior to the establishment of the alternative cropping systems project, the area was used for several smaller scale experiments of varying duration. The previous land use may be expected to influence the distribution of weed populations and soil fauna.

This paper seeks to characterize the initial spatial variation in weed populations and soil fauna and determine if this variation can be correlated with the observed variation in soil chemical, soil physical, topographic and previous land use factors.

Methods

Weed Data

Weed populations were assessed in each plot in June 1994, prior to in-crop herbicide application, and in August 1994, to assess the residual populations. At each assessment time, weeds were counted and identified in twenty 0.5m X 0.5m quadrats in each plot. Five quadrats were randomly placed in each quadrant of each plot. All common weed species identified at each count were included in subsequent analyses (Table 1).

Table 1. Common weed species included in the analyses of the June, August and seedbank weed counts.

Common Name	Scientific Name	June	August	Seedbank
American dragonhead	*Dracocephalum parviflorum* Nutt.	✓		
American vetch	*Vicia americana* Muhl. Ex. Willd.	✓	✓	✓
Annual sow-thistle	*Sonchus oleraceus* L.		✓	
Biennial wormwood	*Artemisia biennis* Willd.			✓
Bluebur	*Lappula squarrosa* (Retz.) Dumort.			✓
Canada thistle	*Cirsium arvense* (L.) Scop.	✓	✓	✓
Cleavers	*Galium aparine* L.		✓	
Common groundsel	*Senecio vulgaris* L.			✓
Common pepper-grass	*Lepidium densiflorum* Schrad.	✓	✓	✓
Dandelion	*Taraxacum officinale* G. H. Weber ex Wiggers	✓	✓	✓
Flixweed	*Descurainia sophia* (L.) Webb ex Prantl	✓	✓	✓
Foxtail barley	*Hordeum jubatum* L.		✓	✓
Goat's-beard	*Tragopogon dubius* Scop.		✓	
Green foxtail	*Setaria viridis* (L.) P. Beauv.	✓	✓	✓
Lamb's-quarters	*Chenopodium album* L.	✓	✓	✓
Narrow-leaved hawk's-beard	*Crepis tectorum* L.	✓	✓	✓
Night-flowering catchfly	*Silene noctiflora* L.			✓
Pale smartweed	*Polygonum lapathifolium* L.	✓		
Perennial sow-thistle	*Sonchus arvensis* L.	✓	✓	✓
Pineappleweed	*Matricaria discoidea* D. C.	✓		
Prickly lettuce	*Lactuca serriola* L.			✓
Prostrate knotweed	*Polygonum aviculare* L.	✓	✓	✓
Prostrate pigweed	*Amaranthus blitoides* S. Watson	✓	✓	✓
Quack grass	*Elytrigia repens* (L.) Desv. ex B. D. Jacks		✓	✓
Redroot pigweed	*Amaranthus retroflexus* L.	✓	✓	✓
Round-leaved mallow	*Malva pusilla* Sm.			✓
Russian thistle	*Salsola kali* L. subsp. *ruthenica* (Iljin) Soó	✓	✓	✓
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	✓	✓	✓
Stinkweed	*Thlaspi arvense* L.	✓	✓	✓
Thyme-leaved spurge	*Euphorbia serpyllifolia* Pers.			✓
Volunteer alfalfa	*Medicago sativa* L.		✓	
Volunteer barley	*Hordeum vulgare* L.			✓
Volunteer canola	*Brassica napus* L. and *B. rapa* L.	✓	✓	✓
Volunteer flax	*Linum usitatissimum* L.	✓	✓	
Volunteer lentils	*Lens culinaris* Medic.	✓	✓	✓
Volunteer wheat	*Triticum aestivum* L.		✓	✓
Wild buckwheat	*Polygonum convolvulus* L.	✓	✓	✓
Wild mustard	*Sinapis arvensis* L.	✓		✓
Wild oats	*Avena fatua* L.	✓	✓	✓
Wild tomato	*Solanum triflorum* Nutt.	✓		✓

The weed seedbank was sampled in April 1995 prior to the initiation of any of the spring treatments. Fall cultivation had occurred in the high and organic input plots, while no treatments had been carried out on the reduced input plots. Twenty soil cores with 5 cm diameter and 10 cm depth were taken per plot, five randomly placed in each quadrant. The samples were subjected to three cycles of freezing and germination in the greenhouse. See Derksen (1999) for details. Weed species that are included in subsequent analyses are listed in Table 1.

Soil Fauna Data

Soil fauna were sampled from soil cores taken from odd numbered plots on May 2, 1995. Four soil cores with 4 cm diameter and 15 cm depth were taken per plot, and bulked. Water-borne soil microfauna were extracted using Baermann funnels from a 30 g portion of each sample. The sample is placed in a glass funnel and covered with water. Light and heat is then used to force the water-born organisms into the funnel stem. The water is drained into a vial and examined under a stereo microscope with a black background to enable the detection of moving organisms. The organisms were classified as Nematodes, Rotifers, Enchytraeids, Protozoans or other groups. Soil mesofauna was extracted using Tullgren funnels from the remainder of the sample. This technique uses light and heat to force soil fauna including Nematoda, Enchytraeidae, Acari, Aranea, Cellembola, Thysanoptera, Sminthuridae, Diptera and Coleoptera into vials of alcohol. The mites (Acari) were divided into sub-orders Oribatida, Gamasida, Actinedida and Acaradida.

Soil Physical, Soil Chemical and Topographic Factors

Soil samples and measurements were taken at 160 locations within the project area in the site characterization year (Selles et al. 1999). The distances between sample sites were varied to enable the use of geostatistical procedures to describe the spatial variation in soil properties.

Table 2. Range of values for soil physical, soil chemical, topographical and land use factors included in analyses.

	Factor	Minimum	Maximum
Soil Physical	Bulk density (mg/m^3)	1.11	1.22
	Horizontal conductivity (mS/m)	13.44	27.58
	Vertical conductivity (mS/m)	14.89	31.60
	Aggregate diameter (mm)	0.20	0.38
	Erodible fraction (%)	9.95	28.39
	Sand (%)	62.84	79.88
	Silt (%)	13.71	26.28
	Clay (%)	4.73	13.59
Soil Chemical	Organic carbon (mg/ha)	23.54	40.64
	Total nitrogen (g/kg)	2.32	3.74
	Carbon/nitrogen ratio	10.00	10.75
	pH	4.59	5.79
Topographic	Elevation (m)	663.62	667.77
	Profile curvature (°/m)	-0.02	0.01
	Planar curvature (°/m)	-1.11	1.58
Land Use	Alternative crops experiment (years)	0	2.0
	Green manure management experiment (years)	0	2.0
	Winter wheat experiment (years)	0	2.0
	Annual legume green manure experiment (years)	0	3.0
	Continuous wheat experiment (years)	0	2.0
	Total area in experiments (years)	0	5.0
	Cereal filler (years)	1.0	8.0
	Fallow filler (years)	0	2.0

The soil physical factors measured were bulk density, horizontal conductivity, vertical conductivity, mean aggregate diameter, erodible fraction, percent sand, percent silt and percent clay (Table 2). Bulk density was measured from 0 to 7.5 cm. Vertical conductivity is measured from 0 to 1.5 m, while horizontal conductivity is measured to 0.75 m. Aggregate size was measured from samples taken to a 5 cm depth. The erodible fraction is composed of aggregates less than 0.84 mm. Details are available in Moulin and Selles (1999). Vertical and horizontal conductivity were highly correlated indicating uniformity at sampling sites (Table 3). High correlations also exist between various factors measuring aggregate size.

Table 3. Correlation coefficients (r) between all pairs of factors analyzed. Factors are grouped as soil physical, soil chemical, topographic and land use. All pairs of factors with r^2>0.50 are bolded.

Factor		BD	HC	VC	AD	EF	Sd	St	Cl	OC	TN	CN	pH	El	Pr	Pl	AC	GM	WW	AL	CW	TE	CF	FF
Bulk density	BD	1.00																						
Horizontal conductivity	HC	-0.14	1.00																					
Vertical conductivity	VC	-0.11	0.93	1.00																				
Aggregate diameter	AD	0.17	-0.50	-0.54	1.00																			
Erodible fraction	EF	0.18	-0.33	-0.40	0.58	1.00																		
Sand	Sd	0.21	-0.38	-0.44	0.90	0.64	1.00																	
Silt	St	-0.32	0.32	0.36	-0.63	-0.55	-0.88	1.00																
Clay	Cl	0.02	0.27	0.32	-0.77	-0.43	-0.71	0.16	1.00															
Organic carbon	OC	-0.37	-0.24	-0.33	0.43	0.23	0.33	0.05	-0.59	1.00														
Total nitrogen	TN	-0.37	-0.34	-0.42	0.53	0.28	0.38	-0.01	-0.61	0.96	1.00													
C/N ratio	CN	-0.35	-0.01	-0.07	-0.06	-0.12	-0.16	0.40	-0.18	0.55	0.44	1.00												
pH	pH	0.22	-0.16	-0.18	0.35	0.12	0.27	0.01	-0.44	0.24	0.23	0.14	1.00											
Elevation	El	0.25	0.46	0.55	-0.53	-0.32	-0.30	0.00	0.50	-0.74	-0.79	-0.47	-0.29	1.00										
Profile curvature	Pr	0.14	0.06	0.09	0.02	-0.03	0.04	-0.07	0.00	[illegible]	-0.16	-0.03	-0.04	0.12	1.00									
Planer curvature	Pl	-0.12	-0.08	-0.06	0.02	0.05	-0.03	0.10	-0.05	0.09	0.12	0.10	0.14	-0.15	-0.61	1.00								
Alternative crops exp.	AC	-0.29	0.21	0.18	-0.32	-0.08	-0.40	0.47	0.11	0.17	0.16	0.30	-0.09	-0.18	-0.19	0.18	1.00							
Green manure management exp.	GM	0.02	-0.44	-0.49	0.27	0.18	0.15	-0.02	-0.22	0.26	0.31	0.01	0.10	-0.43	0.01	-0.06	-0.15	1.00						
Winter wheat experiment	WW	-0.06	-0.11	-0.12	0.13	-0.14	0.02	0.08	-0.12	0.22	0.24	0.21	0.19	-0.22	-0.01	0.00	0.04	-0.04	1.00					
Annual legumes green manure exp	AL	0.01	-0.30	-0.37	0.33	0.17	0.24	-0.15	-0.23	0.12	0.20	-0.14	0.07	-0.46	0.08	0.00	-0.12	0.25	-0.07	1.00				
Continuous wheat exp	CW	-0.12	-0.25	-0.19	0.27	0.07	0.20	-0.24	-0.06	0.19	0.27	0.00	-0.05	-0.22	0.01	0.01	-0.08	-0.11	-0.05	-0.08	1.00			
Total area in experiments	TE	-0.24	-0.43	-0.51	0.28	0.10	0.06	0.12	-0.25	0.45	0.54	0.17	0.16	-0.77	-0.07	0.08	0.27	0.65	0.11	0.62	0.12	1.00		
Cereal filler	CF	0.25	0.39	0.48	-0.24	-0.09	-0.03	-0.15	0.23	-0.43	-0.51	-0.18	-0.15	0.74	0.08	-0.08	-0.29	-0.65	-0.10	-0.61	-0.07	-0.99	1.00	
Fallow filler	FF	0.40	0.27	0.36	-0.18	-0.09	0.00	-0.30	0.34	-0.61	-0.62	-0.49	-0.30	0.78	0.09	-0.11	-0.37	-0.48	-0.21	-0.36	0.01	-0.89	0.89	1.00

Organic carbon, total nitrogen, carbon/nitrogen ratio and pH, were the soil chemical factors that were tested for correlations with the weed and soil faunal data (Table 2). All soil chemical factors were calculated from soil cores taken from 0 to 7.5 cm. Details are available in Selles et al. (1999). Organic carbon and total nitrogen have a high positive correlation with each other, and negative correlations with elevation (Table 3).

Elevation, profile curvature and planar curvature were the topographic factors included to potentially explain variability in weed populations and soil fauna (Table 2). Planar curvature is curvature in the horizontal plane (a measure of curvature of contours) and profile curvature is curvature in the vertical direction (downhill or uphill rate of change in slope in the gradient direction). Planar and profile curvature were calculated with a nugget effect variogram based on elevation measured during the site characterization year (Moulin and Selles 1999).

Values for most physical soil factors and planar and profile curvature were estimated for each plot with block kriging, using 3x3, two-dimensional Gaussian-Quadrature as implemented in Surfer (Surfer version 7). Block kriging was conducted using spherical variograms calculated with Genstat (Gentstat 5 version 4.1). Data were not detrended prior to calculation of the semivariograms, as spatial trends were judged to be not significant.

Values for all soil chemical factors, aggregate diameter, bulk density and elevation were calculated for each plot with a 4x4 block kriging procedure for an area delimited by the plot size. Semivariograms for these variables were based on an exponential model. Calculations for semivariograms and kriging were done with MGAP v 1.04 (RockWare Inc., 1993).

Land Use Factors

Land use for the preceding eight years was determined from Scott Research Farm records. In 1993, the entire site was cropped to barley. From 1986 to 1992, five multi-year experiments were conducted on the project area (Figures 1-5, Table 2). The number of years between 1986 and 1994 that each ACS plot was involved each of these experiments was calculated. The years in each experiment was weighted by the portion of each plot involved in the experiment. The time in each multi-year experiment was recorded as a separate variable to determine if any of the experiments altered the weed and soil faunal communities.

The most recent multi-year experiment was conducted from 1990 to 1992 studying alterative crops (Figure 1). The areas involved in this project were cropped to a variety of alternative crops in the first year, followed by wheat in the second year. The project was conducted for two years on two different portions of the alternative cropping project, influencing 24 plots. A green manure management project following a two-year rotation of lentil and wheat was conducted on the alternative cropping site from 1987 to 1992 (Figures 1-4). The project was established on different plots from 1987-1990. A winter wheat experiment was conducted from 1986 to 1988 (Figures 3-5).

Two of the multi-year experiments started prior to 1986. From 1984 to 1990, an annual legume/green manure experiment was carried out (Figures 1-5). This experiment followed a three year rotation of lentil, wheat and barley.

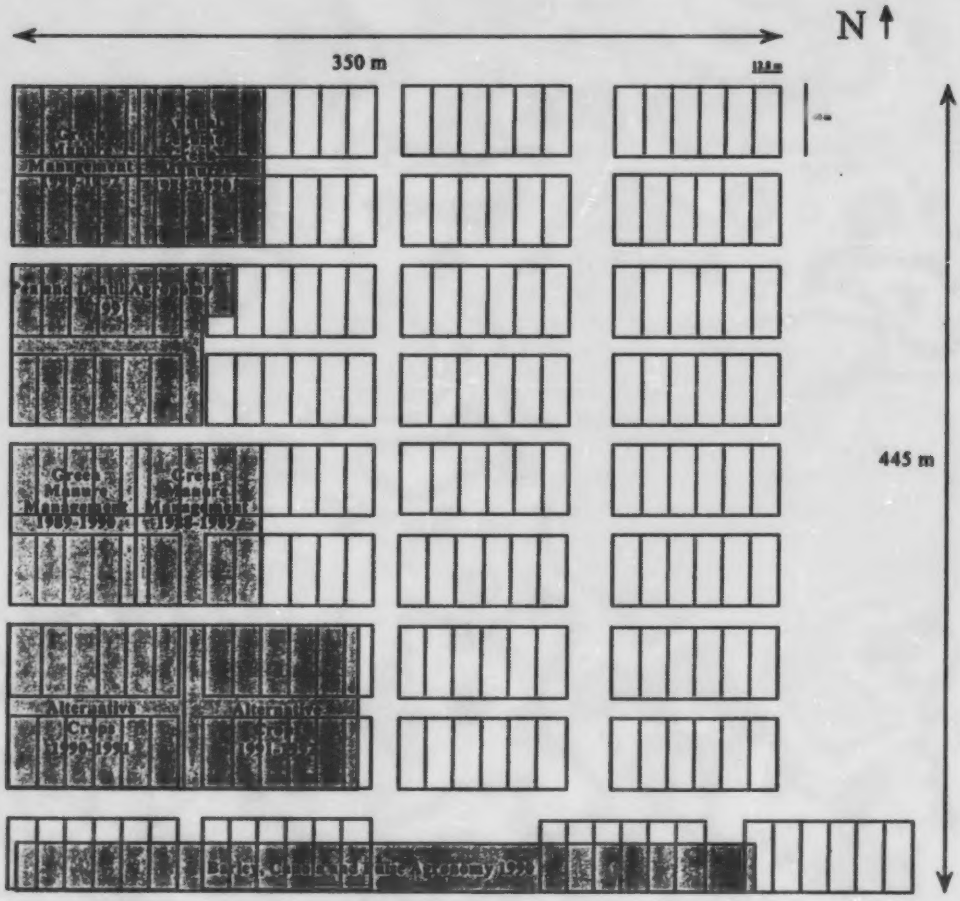

N
350 m
445 m
416 m
Management
Green Manure Management 1989-1990
Green Manure Management 1988-1989
Alternative Crops 1990-1991
Alternative
Barley

Figure 1. ACS site land use from 1990 to 1992. Areas not being used for experiments were cropped to barley during this period.

On two sites within the alternative cropping area the rotation was completed once, and on one site the rotation was completed twice. A continuous wheat experiment established in 1982 ended in 1987 (Figures 4-5). This experiment was conducted on the same plots for the entire experimental period. The experiment tested various herbicides in continuous wheat and included check plots which were not sprayed.

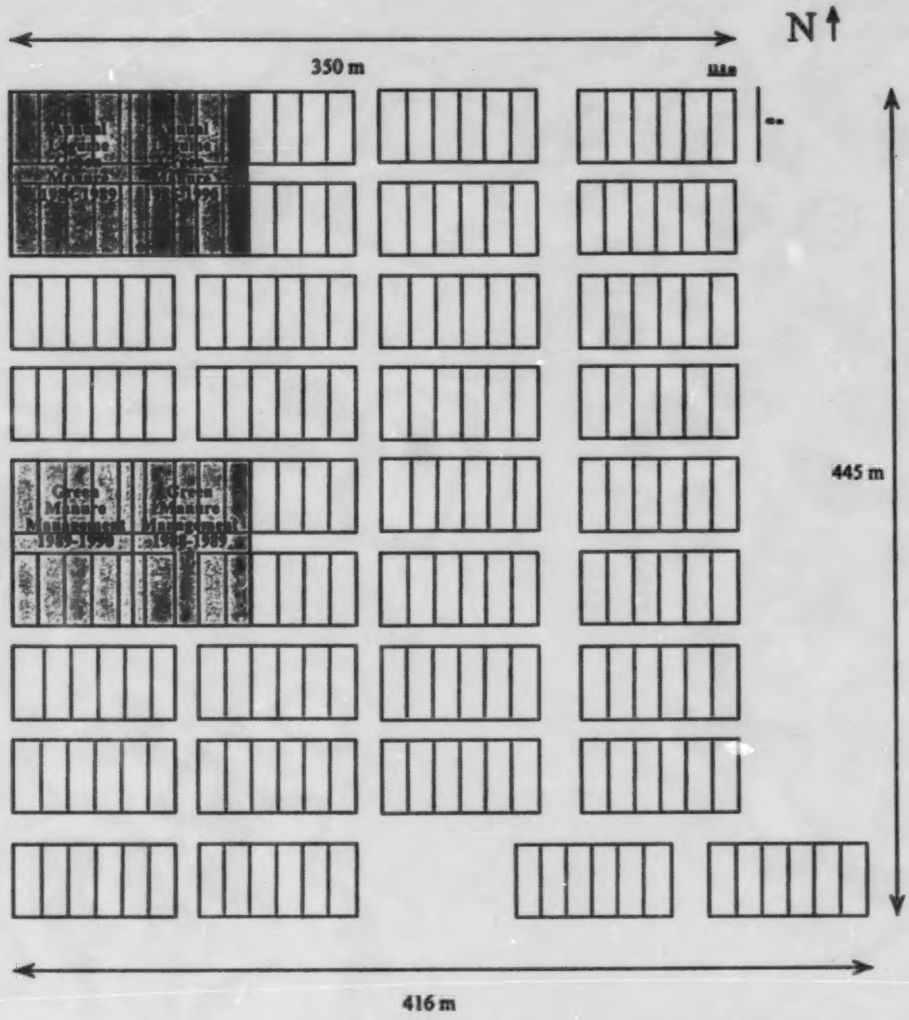

N
350 m
Annual
Legume
Green
Manure
1988-1989
Annual
Legume
Green
Manure
1989-1990
Green
Manure
Management
1989-1990
Green
Manure
Management
1988-1989
445 m
416 m

Figure 2. ACS land use in 1989. Areas not being used for experiments were cropped to barley during this period.

Between 1986 and 1994, six one-year experiments were also conducted on the project area (Figures 1-5). These experiments were: pea and lentil agronomy in 1991, barley, canola and pulse agronomy in 1990, stubble experiments in 1988, seed placed urea in 1988, pulse/oilseed intercropping in 1987 and sweet clover in 1986. The area that was not used for experiments was cropped to cereals (barley or oats) or fallowed. The total number of years each plot was cropped to cereal, fallowed or used for experiments (multi-year or single year) were included as three additional variables (Table 2). These variables were highly correlated with each other and elevation (Table 3).

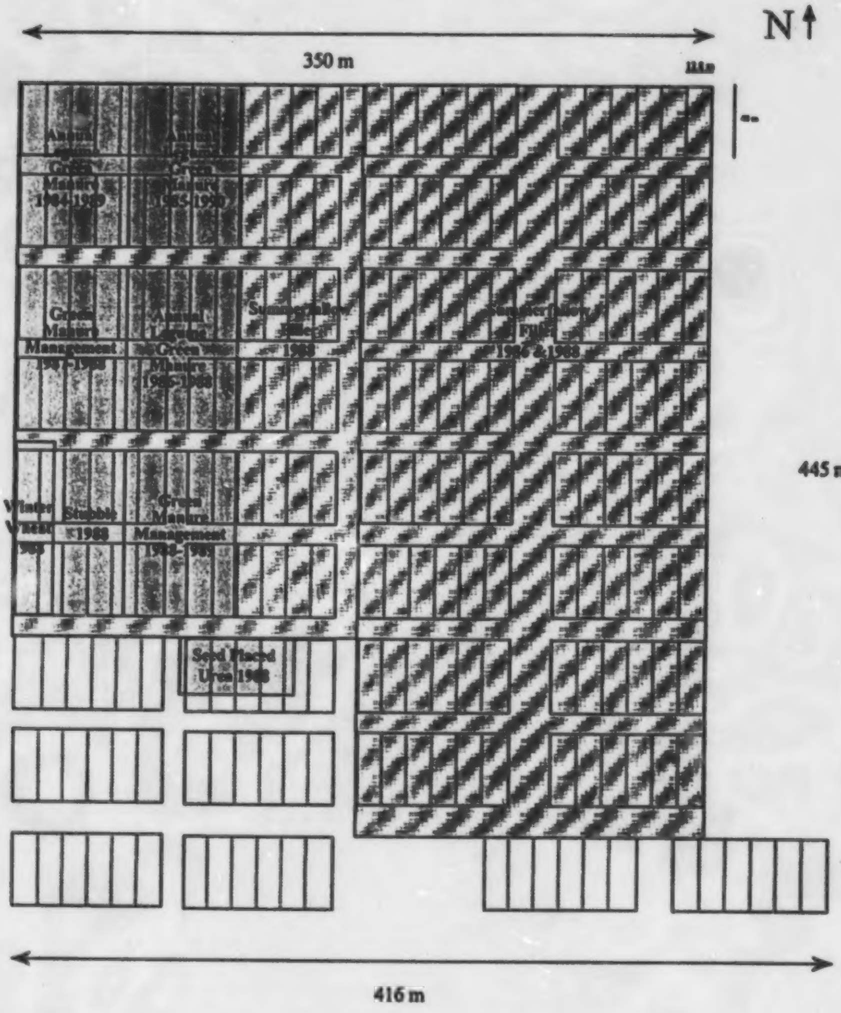
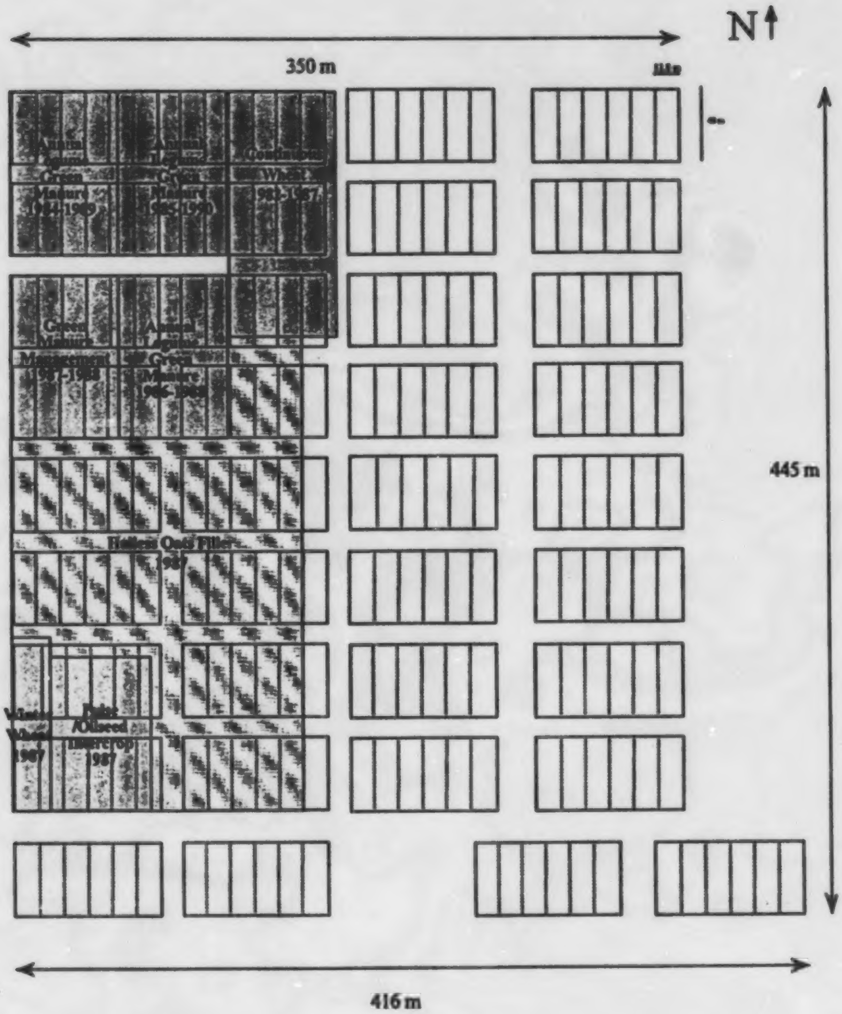
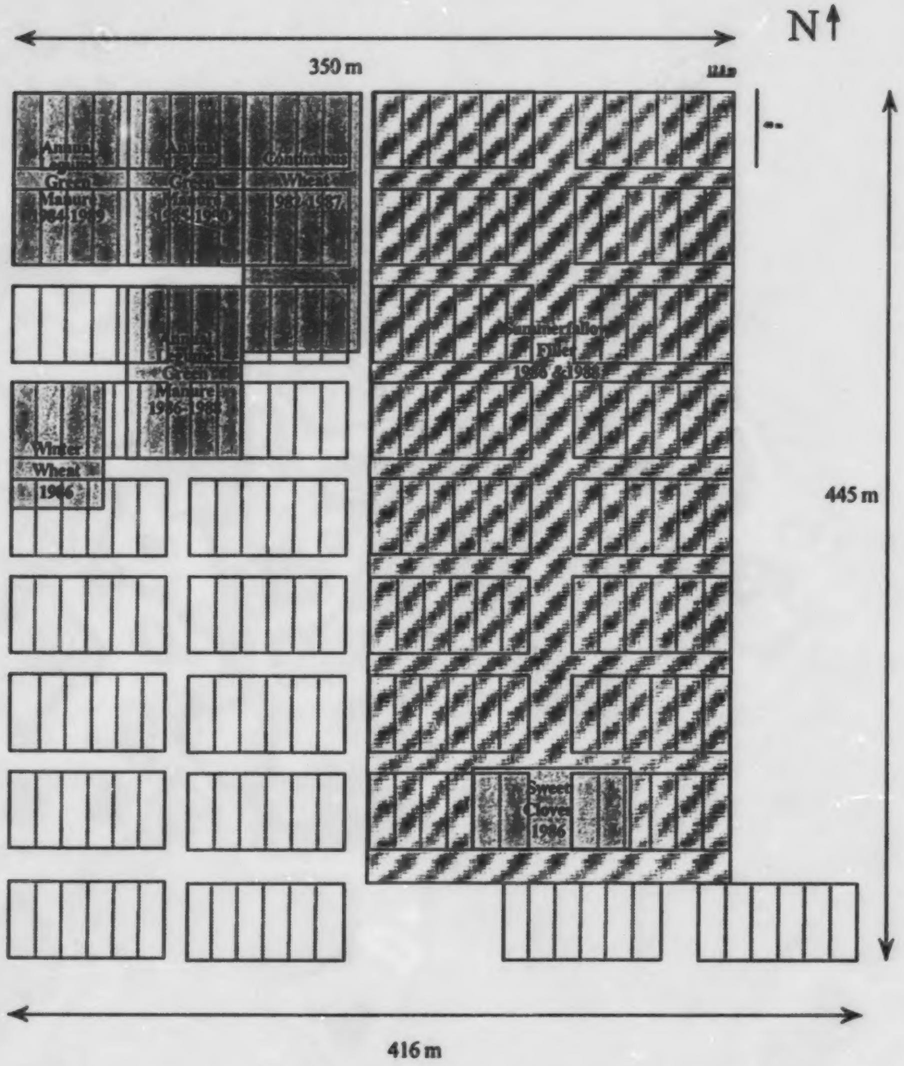

N
350 m
Annual Legume Green Manure 1984-1989
Annual Legume Green Manure 1985-1990
Green Manure Management 1987-1988
Annual Legume Green Manure 1986-1988
Summerfallow Tillage 1988
Summerfallow Tillage 1986 & 1988
Winter Wheat 1988
Stubble 1988
Green Manure Management 1988-1989
Seed Placed Urea 1988
445 m
416 m

Figure 3. ACS land use in 1988. Areas not being used for experiments were either summerfallowed (as indicated) or cropped to barley.



N
350 m
Annual Legume Green Manure 1984-1989
Annual Legume Green Manure 1985-1990
Continuous Wheat 1983-1987
Green Manure Management 1987-1988
Annual Legume Green Manure 1986-1989
Hulless Oats Filler 1987
Winter Wheat 1987
Pulse /Oilseed Intercrop 1987
445 m
416 m

Figure 4. ACS land use in 1987. Areas not being used for experiments were cropped to either hulless oats (as indicated) or barley.



N
350 m
445 m
416 m
Annual Legume Green Manure 1984-1989
Annual Legume Green Manure 1985-1990
Continuous Wheat 1982-1987
Annual Legume Green Manure 1986-1988
Winter Wheat 1986
Summerfallow Filler 1986 & 1988
Sweet Clover 1986

Figure 5. ACS land use in 1986. Areas not being used for experiments were either summerfallowed (as indicated) or cropped to barley.

Spatial Pattern Model

A cubic trend surface was used as the basis for the spatial model for the weed populations and soil fauna. This model is able to capture both linear gradients patterns across the site and the more complex patterns of patches and gaps (Legendre 1990):

$$z = x + y + x^2 + y^2 + x^2y + xy^2 + x^3 + y^3$$

Each term on the cubic trend surface was determined for each plot where x is the easting position and y is the northing position of the center of each plot relative to plot 1. Each term was entered as a separate variable in the analysis.

Replicate blocks were also included as four separate variables to help explain spatial variance. The inclusion of replicate block as a factor in the analysis enabled an evaluation of the relative ability of this more traditionally used variable for explaining variance in univariate analyses (ie. ANOVAs).

Partitioning the Variance and Ordinations

The variance in the weed and soil faunal data attributable to each factor or group of factors is determined using redundancy analysis (RDA) in the program CANOCO (ter Braak and Šmilauer 1998). RDA is a constrained form of principal components analysis (PCA) in which the weed and soil faunal data are constrained to be linear combinations of the factors of interest. The use of the RDA procedure allows the generalization of univariate regression to a multivariate case. By running separate RDAs constrained by each factor, it is possible to determine the relative ability of each factor to explain the variance in each weed and soil faunal data set. Prior to the analyses, the densities of all species were log transformed (lnx+1) prior to analysis to reduce the influence of plots with species found in relatively high densities. Following convention, the samples were neither centered nor standardized. Species were weighted inversely to error variance that remains after fitting species to environmental and covariable data. The factors analyses are recorded as quantitative data, therefore, the ordinations were scaled to emphasize inter-species relationships so that the resulting ordination is able to reflect the correlations amongst the environmental variables. Species scores were divided by standard deviation so that species with large variances do not dominate the ordination.

The significance of the variance attributable to each factor of interest is determined using reduced model Monte Carlo permutation tests. In a Monte Carlo permutation, the species data are randomly assigned to the environmental data 999 times and the RDA is rerun each time. The proportion of times the random data explains more variance in the species data is used to determine the significance of the factor. The variance that each significant factor is able to explained singly is presented for each data set as a percentage of the total explained variance.

The forward selection procedure within RDA was used to develop both spatial and factor models including only significant variables. Only variables with significant marginal variances were considered for inclusion in final models. Variables that were able to explain the highest amount of significant variance were added to the model following a stepwise forward selection procedure. Variables that were highly correlated with those already included in the model were excluded following this method. The total explained variance reported for each population included all variance explained by the spatial and factor models. The variance explained by individual factors or models are expressed as a percentage of the total explained variance. Unexplained variance may be attributable to "noise" in the data set or unmeasured factors.

The variance in the weed and soil faunal data that is accounted for by each model and the interaction of the models can be determined through partitioning of the variance (Legendre and Legendre 1998). The percentage variance in the weed and soil faunal data set accounted for by each model is determined by constraining the weed and soil faunal data by the model of interest. The ability of each model to explain unique variance is determined by treating the variables in the other model as a covariables within a partial RDA. For example, a partial RDA removes the proportion of the variance in the weed and soil faunal data attributable to the interaction of the spatial model with the factor model by removing the spatial model variables as covariables. Subtraction of the variance explained by the factor model without covariables from the variance explained by the factor model using the spatial model as covariables produced the variance explained by the interaction of the two models.

The results of the RDA of each weed population and soil fauna data set constrained by the factors chosen by forward selection are presented as ordinations. The factors that were marginally significant but excluded from the model are plotted passively, after the analysis was complete. In the ordinations, factor vectors point toward species that have large amounts of variance explained by that factor. The length of the vectors indicates relative ability of the factor to explain the variance observed in the weed populations and soil fauna. The significance of each axis was determined using Monte Carlo tests.

Results and Discussion

Weed Populations

All factors in the cubic trend surface were retained for the spatial model in the June and seedbank weed counts; however, east-west variables (x, x^2, x^3) did not significantly contribute to the explanation of variance in the August weed populations and were excluded from the spatial model. The spatial model and the factor model together were able to explain from 23-37% of the variance in the weed population data. (Table 4). The spatial model accounted for just over half of the explained variance in each of the weed data sets. The cubic trend surface (including interaction) accounted for approximately 50% of the explained variance in the weed populations. Replicate block (including interaction) was only able to explain about 15% of the explained variance in the weed populations. The majority of the variance explained by replicate block was also explained by the cubic trend surface; however, replicate block was also able to account for an additional 5 % not explained by the cubic trend surface.

Table 4. Percent of explained variance in weed populations attributable to spatial model.

Source of variation	June	August	Seedbank
Replicate Block	5.1	6.3	4.9
Cubic Trend Surface Model	38.5	42.3	46.2
Interaction	11.5	8.7	10.7
Spatial Model	55.1	57.3	61.8
Total Explained	37.4	28.6	22.5

Most of the soil physical factors explained a significant portion of the variance in each of the weed population data sets (Table 5). The least important soil physical factor in each data set was erodible fraction, which did not contribute significantly to the explained variation in either the June or seedbank data set. Bulk density, aggregate diameter and percent clay were the most important soil physical factors in the June, August and seedbank data sets, respectively. Each of the soil chemical factors were also able to explain a significant portion of the variance in the each of the weed assessments. In all the weed population data sets, total nitrogen explained the largest amount of variation out of all the soil chemical variables. The only topographic factor that explained a significant portion of the variation in all the weed populations was elevation. Planar curvature was able to explain a significant amount of variation in the seedbank data set.

Table 5. Percent of explained variance in the weed populations attributed to significant factors singly. Significance of variance indicated by: *** $=P\geq0.001$, **$=P\geq0.01$, *$=P\geq0.05$, ns$=P\leq0.05$.

	Factor	June	Residual	Seedbank
Soil Physical	Bulk density	6.7 ***	5.6 ***	3.6 *
	Horizontal conductivity	3.5 ***	5.6 ***	4.9 ***
	Vertical conductivity	4.0 ***	6.3 ***	5.3 ***
	Aggregate diameter	4.0 ***	11.2 ***	7.6 ***
	Erodible fraction	ns	3.1 **	ns
	Sand	3.2 **	7.7 ***	4.0 **
	Silt	4.0 ***	5.6 ***	4.4 ***
	Clay	4.3 ***	7.7 ***	8.0 ***
Soil Chemical	Organic carbon	6.1 ***	5.2 ***	10.2 ***
	Total nitrogen	8.6 ***	7.0 ***	12.4 ***
	Carbon/nitrogen ratio	4.0 ***	7.0 ***	4.4 ***
	pH	5.9 ***	6.3 ***	6.2 ***
Topographic	Elevation	9.4 ***	9.1 ***	11.6 ***
	Profile curvature	ns	ns	ns
	Planar curvature	ns	ns	5.3 *
Land Use	Alternative crops experiment	6.4 ***	4.9 ***	ns
	Green manure management experiment	3.5 ***	4.5 ***	4.4 **
	Winter wheat experiment	3.7 *	6.3 **	5.3 *
	Annual legume green manure experiment	9.1 ***	10.8 ***	9.3 ***
	Continuous wheat experiment	6.4 ***	5.2 ***	8.4 ***
	Total area in experiments	11.0 ***	8.0 ***	9.8 ***
	Cereal filler	10.2 ***	8.0 ***	9.3 ***
	Fallow filler	8.3 ***	7.0 ***	8.0 ***

The previous land use factors explained a large proportion of the variance in the weed populations (Table 5). The total area in experiments, area in cereal filler and area in the annual legume green manure experiments explained the largest percentage of the variance. Experiments that used the same land area for longer periods of time had larger influences on the weed populations.

Between 26% and 37% of the explained variance in the weed populations was attributable to the interaction of the spatial and factor models (Table 6). The factor model (including interaction) was able to account for approximately 76%, 80% and 65% of the explained variance in the June, August and seedbank weed populations, respectively The higher amount of variance attributable solely to the spatial model in the seedbank counts indicates that the seeds are more evenly distributed in the field than indicated by the field weed counts. Harvest would aid the dispersal of seeds within the plot area. Also, factors restricting the germination of species in the field being removed in the seedbank samples. For example, differences in available moisture influenced by elevation would not be a factor in seedbank counts.

Table 6. Percent of explained variance in weed populations attributable to spatial and factor models.

Source of variation	June	August	Seedbank
Spatial Model	23.8	20.2	35.6
Factor Model	44.7	42.7	38.7
Interaction	31.6	37.1	26.2
Total Explained	37.4	28.6	22.5

The majority of weed species found in June were associated with areas in which the previous land use included experiments. Flax was planted in both the pulse-oilseed intercrop experiment in 1987 and the alternative crops experiment in 1990 and 1991. The area used for the pulse-oilseed intercrop experiment was subsequently used for the green manure management experiment and was adjacent to the winter wheat experiment (Figures 1-4). Figure 6a suggests that volunteer flax may be associated with all these experiments; however, Figure 6b implies that the majority of the volunteer flax found in the June 1994 counts was likely introduced in the 1987 experiments. Shepherd's-purse and prostrate pigweed are associated with all experiments (Figure 6a). These species are difficult to control in the roadways between plots. Shepherd's-purse was more strongly associated with the experiments conducted along the western edge, while prostrate pigweed was associated with experiments conducted on the northern portion of the area (annual legume green manure and continuous wheat, Figures 2-5). Lamb's-quarters, stinkweed, Russian thistle, wild buckwheat and pale smartweed are also associated with experiments conducted on the northern portion of the area (Figure 6a). Stinkweed and lamb's-quarters were problematic weeds both experiments conducted in this area. Russian thistle was noted as a major weed in the continuous wheat studies. The north-west corner had a sandy patch and higher aggregate diameters. These factors were correlated with the presence of wild buckwheat in the continuous wheat experiment (Figure 6b). Green foxtail and prostrate knotweed were associated with both the continuous wheat experiment and the area commonly planted to cereal filler (Figure 6a). Green foxtail was noted as a troublesome weed in the continuous wheat plots receiving no herbicide. Prostrate knotweed has the strongest association with the percentage of surface clay. Dandelion (Figure 6a) and wild oats (Figure 6b) are associated with the eastern side of the project. Diclofop methyl was used for wild oats control in the filler crops until the early 1990's; however, wild oats were often only damaged by the application enabling the development of a very adequate seedbank (S. Brandt pers. comm.). Wild oats also appears to be associated with the alternative crops experiment. This may be attributable to land use prior to 1986, at which time there was an experiment on this area in which the wild oats was allowed to shatter out.

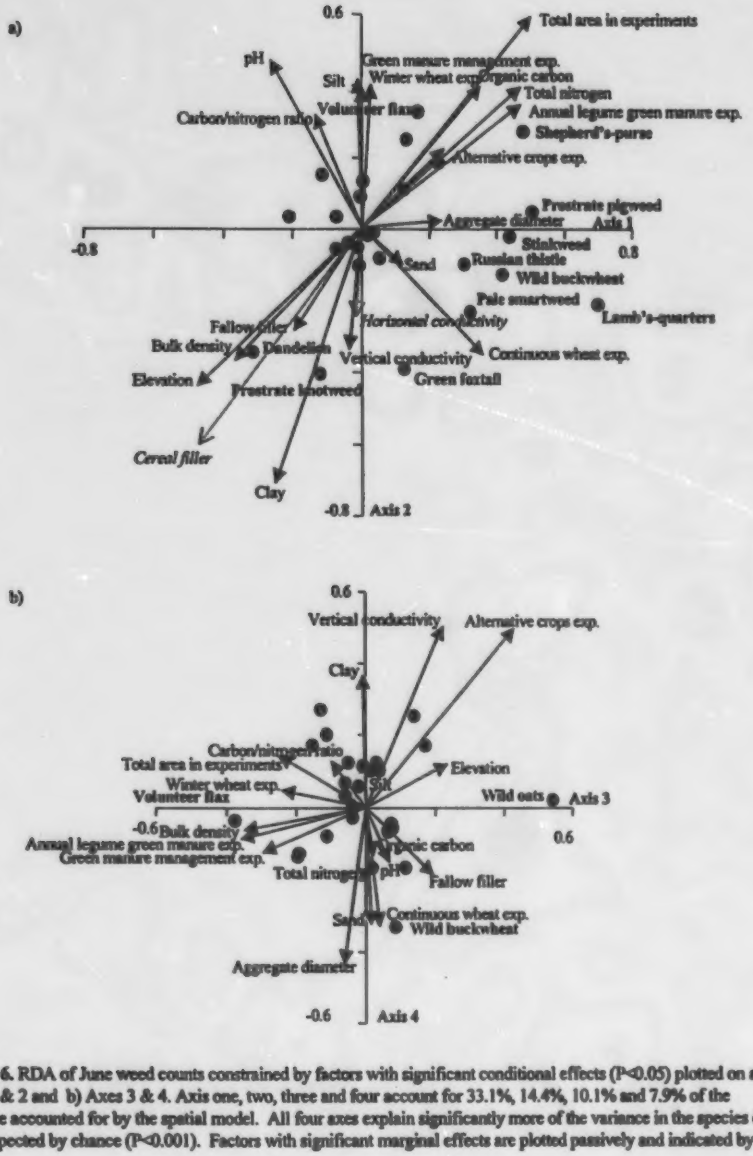


Figure 6. RDA of June weed counts constrained by factors with significant conditional effects ($P<0.05$) plotted on a) Axes 1 & 2 and b) Axes 3 & 4. Axis one, two, three and four account for 33.1%, 14.4%, 10.1% and 7.9% of the variance accounted for by the spatial model. All four axes explain significantly more of the variance in the species data than expected by chance ($P<0.001$). Factors with significant marginal effects are plotted passively and indicated by italics.

The trends observed in the June weed data for wild buckwheat, lamb's-quarters, green foxtail, wild oats and dandelion were also generally present in the August weed data (Figure 7).

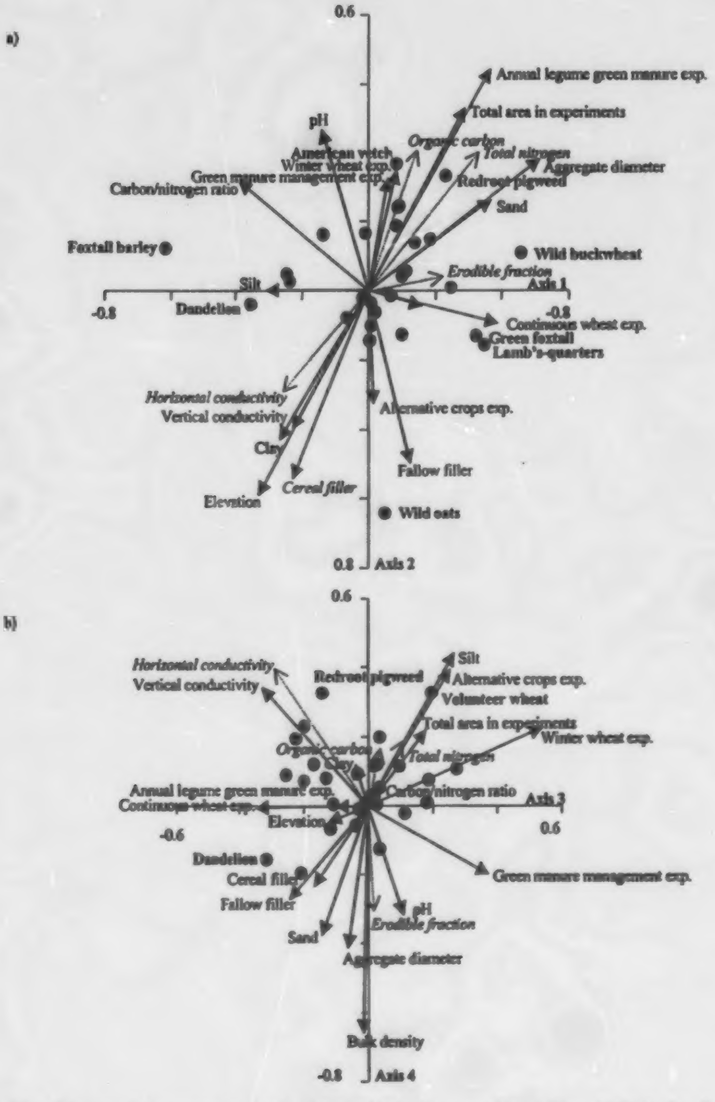


Figure 7. RDA of August weed counts constrained by factors with significant conditional effects ($P<0.05$) plotted on a) Axes 1 & 2 and b) Axes 3 & 4. Axis one, two, three and four account for 25.4%, 20.2%, 11.4% and 9.6% of the variance accounted for by the spatial model. All four axes explain significantly more of the variance in the species data than expected by chance ($P<0.001$). Factors with significant marginal effects are plotted passively and indicated by italics.

The other weeds with strong correlations with the factors in the June data set did not have strong correlations in the August data. These species may have been effectively controlled by the in-crop herbicides applied to the entire area. In the August data set, redroot pigweed was associated with areas previously used for experiments. This species was also positively correlated with high levels of nitrogen and carbon on all four axes. American vetch was associated with the experiments conducted on the western edge of the area. Foxtail barley was associated with the areas not used for experiments. It was also associated with high carbon/nitrogen ratio. Volunteer wheat may have been difficult to distinguish from the crop at the time of the June counts, accounting for it's absence in that data set. This species was associated with the alternative crop experiment in which wheat was most recently planted on all plots in either 1991 or 1992 (Figure 1). Wheat was also planted in 1990 on the green manure management plots that were placed in the same area as the winter wheat experiments (Figures 1,4,5).

As seen in the June counts, prostrate pigweed and shepherd's-purse were associated with areas previously used for experiments in the seedbank counts (Figure 8). The association of wild buckwheat with the factors in the seedbank was similar to observed in the June and August counts (Figure 8a). However, the previously noted association of lamb's-quarters with experiments in the northwest corner may be masking an association of this species with a low carbon/nitrogen ratio (Figure 8b). The seedbank data indicates that Russian thistle is exclusively associated with the continuous wheat experiment and not the annual legume green manure experiment as suggested by the June counts. As previously observed, prostrate knotweed and green foxtail are associated with the continuous wheat experiment and cereal filler (Figure 8a).

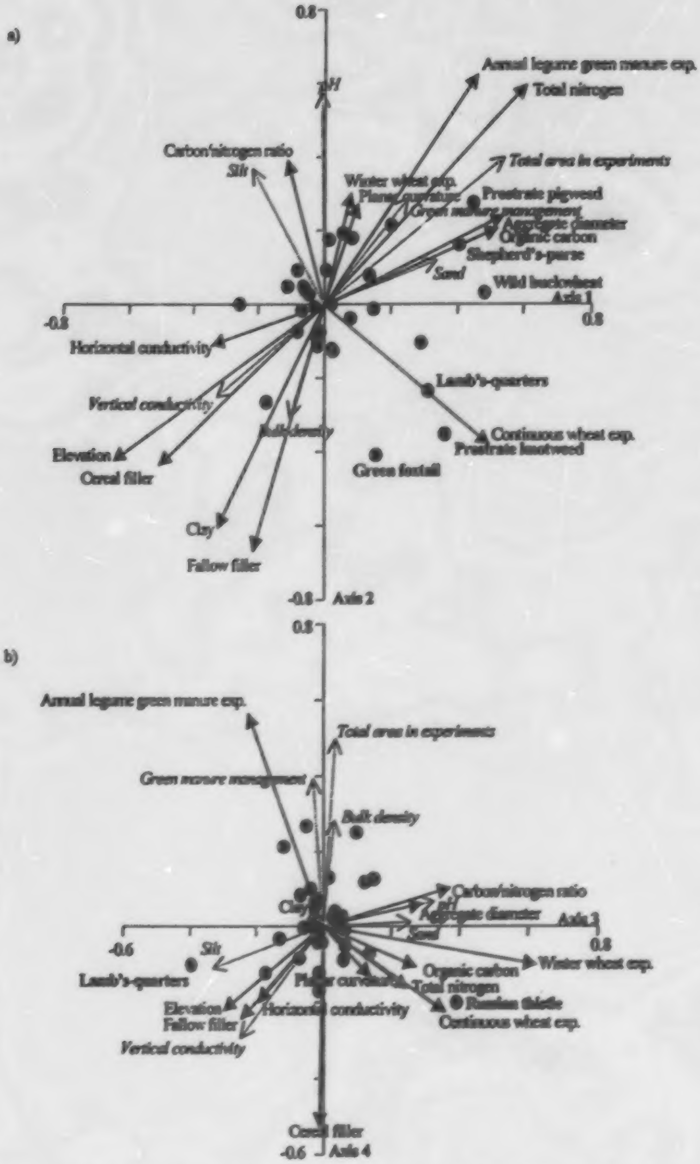


Figure 8. RDA of seedbank counts constrained by factors with significant conditional effects ($P<0.01$) plotted on a) Axes 1 & 2 and b) Axes 3 & 4. Axis one, two, three and four account for 30.1%, 18.5%, 11.6% and 8.9% of the variance accounted for by the model. All three axes explain significantly more of the variance in the species data than expected by chance ($P<0.001$). Factors with significant marginal effects are plotted passively and indicated by italics.

Soil fauna

The significant terms included in the cubic trend surface were x, xy and xy^2 for the mesofaunal data , and x and x^3 for the microfaunal data. The spatial model (both cubic trend model and replicate block) accounted for 71% and 45% of the explained variance in the soil mesofauna and microfauna, respectively (Table 7). Replicate block was able to explain 45% and 40% of the explained variance in the soil mesofauna and microfauna, respectively. The majority of the variance explained by replicate block was also explained by the cubic trend surface; however, replicate block was also able to account for an additional 10-14 % not explained by the cubic trend surface.

Table 7. Percent of explained variance in soil fauna populations attributable to spatial model.

Source of variation	Mesofauna	Microfauna
Replicate Block	13.7	9.7
Cubic Trend Surface Model	26.0	5.2
Interaction	30.9	30.1
Total Spatial	70.6	45.0
Total Explained	20.4	24.9

The only physical factors that influenced the mesofaunal distribution were horizontal and vertical conductivity (Table 8). All the physical factors except bulk density influenced the microfaunal distribution. Aggregate diameter was the single most important variable explaining variance in the soil microfauna, followed by sand and clay. Total nitrogen and organic carbon were able to explain a significant portion of the variation both the microfauna and mesofauna populations. pH did not explain a significant portion of the soil mesofaunal variation and the carbon nitrogen ratio did not significantly contribute to the explanation of the soil microfaunal variance. The only topographic factor that was able to explain variance in both soil fauna was elevation.

Table 8. Percent of explained variance in the soil fauna attributed to significant factors singly. Significance of variance indicated by: *** $=P\geq0.001$, **$=P\geq0.01$, *$=P\geq0.05$, ns$=P\leq0.05$.

	Factor	Mesofauna	Microfauna
Soil Physical	Bulk density	ns	ns
	Horizontal conductivity	14.7 **	22.1 ***
	Vertical conductivity	16.2 **	28.1 ***
	Aggregate diameter	ns	47.8 ***
	Erodible fraction	ns	29.3 ***
	Sand	ns	45.8 ***
	Silt	ns	19.3 **
	Clay	ns	38.6 ***
Soil Chemical	Organic carbon	14.2 **	18.1 **
	Total nitrogen	15.7 **	19.3 **
	Carbon/nitrogen ratio	16.7 **	ns
	pH	ns	16.1 **
Topographic	Elevation	23.5 ***	27.3 ***
	Profile curvature	ns	ns
	Planar curvature	ns	ns
Land Use	Alternative crops experiment	ns	ns
	Green manure management experiment	17.2 ***	23.7 ***
	Winter wheat experiment	10.3 *	ns
	Annual legume green manure experiment	ns	20.9 **
	Continuous wheat experiment	11.3 *	ns
	Total area in experiments	20.1 ***	20.5 ***
	Cereal filler	18.6 ***	19.7 **
	Fallow filler	33.8 ***	18.9 **

The general factors quantifying previous management of the site (filler vs. experiments) were the most important previous land use factors explaining the mesofaunal variance (Table 8). The use of fallow filler was the single most important variable contributing to the explanation of variance in the mesofauna. The general previous land use factors as well as the green manure and annual legume experiments explained a significant proportion of the variance in the microfauna; however, these factors were not as important to the explanation of variance in this data set as the other weed and soil faunal data sets.

Overall, the factor models (including interaction) were able to explain 70% and 85% of the explained variance for the mesofauna and microfauna, respectively (Table 9). The spatial model was able to explain the variance in the mesofauna better than in the microfauna. The mesofauna may be more mobile allowing a more even distribution than seen in the microfauna, which may be more sensitive to soil properties.

Table 9. Percent of explained variance in soil fauna populations attributable to spatial and factor models.

Source of variation	Mesofauna	Microfauna
Spatial Model	29.9	14.9
Factor Model	29.4	55.0
Interaction	40.7	30.1
Total Explained	20.4	24.9

The mesofauna tended to be associated with area not used for experiments (Figure 9a). Orbatita and Gamasida, were associated with high vertical conductivity. High vertical conductivity is indicative of salinity, although the highest levels observed at Scott are a third of those generally considered saline. Nematoda was associated with the fallow filler. Some groups of mesofauna did not show any strong associations, these included Diptera, Aranea, Coleoptera, Sminthuridae, Thysanoptera and Collembola. Several of these groups are quite mobile in the adult stage potentially aiding in their distribution throughout the project area.

Protozoa and rotifers were associated with larger aggregate diameter and sand (Figure 9b). Nematoda in the microfaunal sample showed a moderate response to these factors, but also appeared to be associated with higher organic carbon and nitrogen. The association observed between nematodes and fallow filler in the mesofauna was not present in the microfauna.

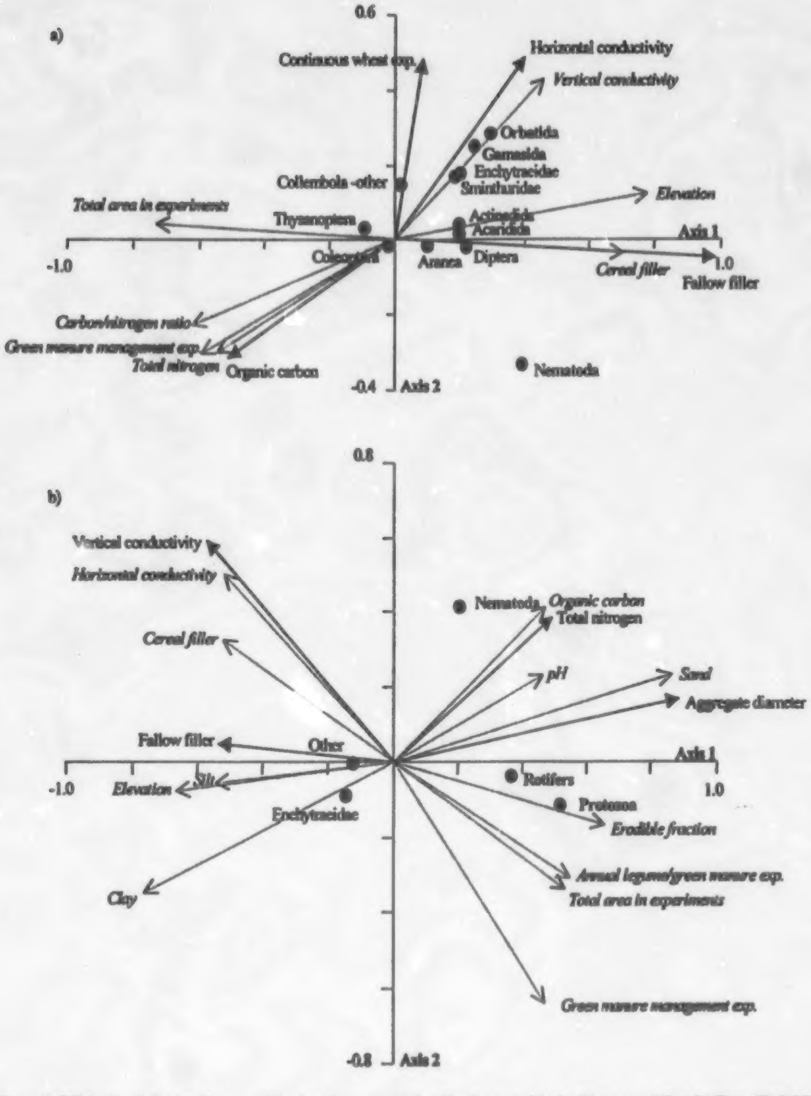


Figure 9. RDA of soil a) mesofauna and b) microfauna constrained by factors with significant conditional effects (P<0.05) plotted on Axes 1 & 2 . Axis one and two account for 49.7% (P<0.001) and 37.1% (P<0.001), and 70.3% (P<0.001) and 27.4% (P=0.001) of the variance accounted for by the spatial model in the mesofauna and microfauna respectively. Factors with significant marginal effects are plotted passively and indicated by italics.

Implications

Given the large variation in weed populations and soil fauna across the site, the site characterization year data will be invaluable for the interpretation of data from the following years. While replicate block does capture some of the variation in the weed populations and soil fauna, a more complex spatial model is necessary. The cubic trend surface is able to explain a larger portion of the variance in the weed and mesofauna than replicate block. Much of the spatial variation is explained by the studied topographic, chemical, physical and previous land use factors. The previous use of the site was particularly important for the weed populations and should be considered when establishing future experiments. A large amount of the variation in the weed populations and soil fauna could be attributed to factors studied that did not follow the spatial model. This suggests that a more complex model should be used when analyzing subsequent years data, incorporating observed plot to plot variation in the site characterization year.

This chapter has documented the initial variation in soil fauna found during site characterization and described the influence of soil, topography and land use on their populations. The results indicate that a great number of factors can influence density, diversity and distribution of fauna in agricultural soils. In addition, there are undoubtedly other biotic factors that may be used to further explain the observed variations. A good example would be the interaction of meso- and micro-fauna with weed populations. Studies have shown that carabid beetles feed on weed seeds, a feature that could influence weed density and mesofauna density and distribution. Also, phytophagous nematodes in the soil may be more abundant in the presence of weeds with extensive root growth patterns. The challenge will be to identify the relationships that determine the key ecological processes such as nutrient cycling, biological pest control and soil and water conservation that are essential for sustainable plant productivity.

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Alternative Cropping Systems

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Scott, Saskatchewan

Potential Indices for Measuring Tillage Intensity and Herbicide Use

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S7N 0X2

Rationale

Farming systems based on reduced inputs and increased diversity of crop types are of interest to producers on the Canadian Prairies as alternatives to conventional systems. For the development of alternative approaches to farming, tools are needed to evaluate and optimize the performance of these cropping systems. Economic indicators are important, but the agronomic and environmental aspects of the systems also need to be considered. Indices can be derived to estimate the impact of various farming practices on the system and its environment. The simplest approach is to construct an index based solely on farm input use records. The next level of complexity is weighted indices that incorporate some knowledge about the farming practices using external data sources. Both of these are examples of state indicators as they measure the actual presence of factors (McRae et al. 2000). The third level of complexity are risk indicators. Risk indicators are estimations based on models. This type of indicator would be obtained by modeling the impact of the farming practices on the environment using several external sources.

The paper presents various methods for calculating herbicide and tillage indices. These indices are used for ranking nine cropping systems found in the Alternative Cropping System Study.

Methods

All indices are average values per plot per year. Values for the indices are presented at the system level; therefore, each index is an average of 24 plots (6 crop phases by 4 replicates) in each of the six years of the first rotation cycle.

The simplest herbicide index is a count of the number of herbicide applications in one year. Tank mixes are considered one application. The weighted herbicide index is kilograms of active ingredient per hectare per year. The modeled index is the Environmental Exposure to Herbicides (EEH). This index accounts for risk to the environment based on exposure of the air, soil and groundwater to herbicides as proposed by the Environmental Exposure to Pesticides index (Vereijken et al. 1995), except that the calculation for the air environmental exposure is based on

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Henry's Law constant rather than vapour pressure (van der Werf 1996). Each component of EEH is calculated for each active ingredient as follows:

EEHair = active ingredient (kg/ha) * Henry's Law constant (Pa m3/moles)
EEHsoil = active ingredient (kg/ha) * soil half life
EEHgroundwater = EEHsoil / mobility (Koc)

Each component of the EEH (air, soil and water) is weighted equally in the final index. To achieve this, the values for active ingredients in each component of the EEH are standardized by the maximum value out of all the active ingredients applied in the study.

EEH = EEHair/ maximum EEHair +EEHsoil/maximum EEHsoil +EEHgroundwater/maximum EEHgroundwater

The simple tillage index is a count of the number of tillage operations per year. In this index, mounted tine harrows and trailed rod are not counted as a separate tillage operations. Also, seeding and banding fertilizer are not included as tillage operations. The weighted index measures the cumulative disturbance in the plots. This additive index of disturbance per year is based on relative disturbance caused by each implement (a value between 0 and 1) as rated by ability to remove fragile residue (Bull 1993). The modeled tillage index measures the percent of crop residue removed per year. This index reflects the relative vulnerability of the cropping system to erosion. The percentage of residue removed is based on residue type (fragile or non-fragile) and type of tillage operation (Bull 1993).

To illustrate the relative usage of tillage and herbicide inputs simultaneously, each index complexity level is plotted against each other. In order to rank the systems, a perpendicular is dropped to a line at 45o between the two axes. This ranking gives the tillage and herbicide indices equal weight.

Results and Discussion

All herbicide indices ranked the systems differently (Figure 1). Reduced input systems applied herbicides more frequently than the high input systems. In general, the reduced input systems included a fall and spring burn-off as well as an in-crop herbicide application.

The number of applications underestimated the relative amount of herbicide active ingredients applied in the high input systems (Figure 1). The in-crop herbicide products necessary to control weed populations in the high input systems tended to contain more active ingredients than the in-crop herbicides used in the reduced input systems. Nevertheless, the reduced input systems still applied more active ingredient than the equivalent high input systems.

Herbicides used in the high input diversified annual grains and high input diversified annual and perennial systems result in higher environmental exposure values than those used in the equivalent reduced input systems (Figure 1). Herbicides in the reduced low diversity system result in higher EEH values than those in the high input low diversity systems, primarily due to chemical fallow in the reduced input low diversity system.

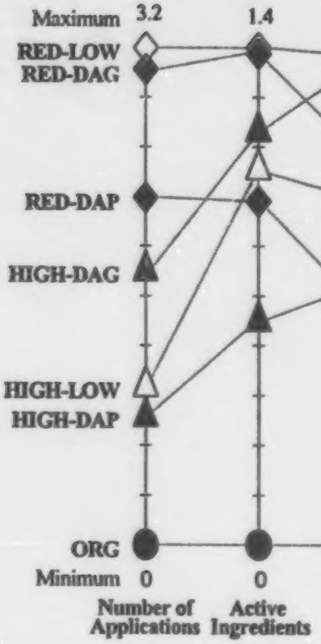

Figure 1. Herbicide indices

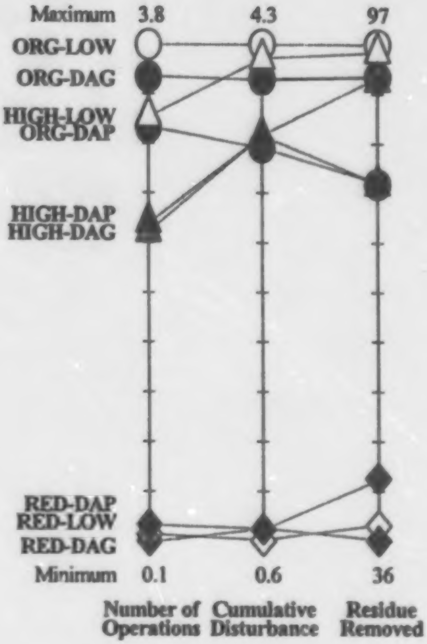

Figure 2. Tillage indices.

All tillage indices ranked the systems differently (Figure 2). The main differences between indices were seen in the relative ranking of the high input systems. Number of operations underestimated the amount of disturbance in the high input systems. Amount of residue removed was similar in the organic and high input systems.

The combination of the simple indices indicated that the lowest inputs were found in the DAP systems, followed by the other organic, reduced and high input systems (Figure 3). The combination of the weighted indices indicate that all the high input systems had higher combined use of herbicide and tillage than the other input levels (Figure 3). The high overall input levels in the high input system indicates that herbicides were used in addition to tillage rather than as a substitution for tillage. When the modeled indices are combined, the high input DAG system has the highest combined input level and reduced input DAP system has the lowest combined input level.

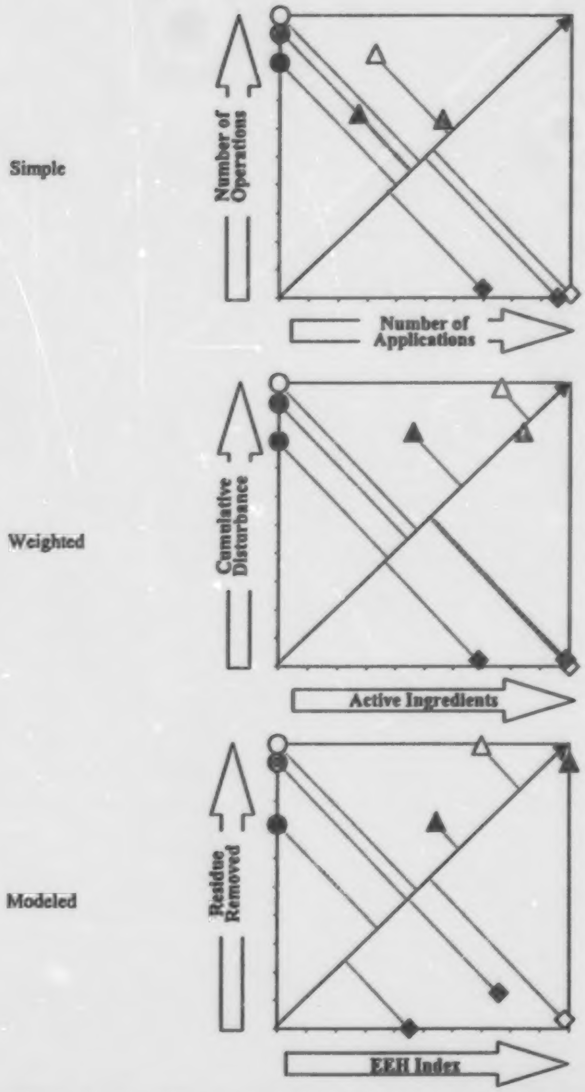

Figure 3. Combined tillage and herbicide indices. Values are scaled identically to Fig. 1 and Fig. 2 and the same symbols are used to identify systems. Ranking along arrow placed at 45° indicates relative combined input levels.

These indices assist in an understanding and interpretation of complex farming systems by synthesizing data for farm input use and environmental risk enabling quantification of the current state of the system. These indices can be used as a tool for management decisions allowing the evaluation of the systems in terms of target levels that need to be achieved as well as thresholds that should not be exceeded.

Selection of indices that can be used as indicators of sustainability requires a concise definition of sustainability. A sustainable farming system should maintain or enhance productivity, reduce production risk, protect the potential of natural resources, be economically viable and be socially acceptable (FAO 1993). The indices developed in this paper consider the potential impact of herbicides and tillage on natural resources and therefore, also the social acceptability of the farming systems. However, the impact of different usage of herbicides and tillage on productivity, production risk and economic viability are not considered. Additional indices must be developed to evaluate the impact of all management decisions on all aspects sustainability for each of the farming systems.

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Data Management Issues Associated with Multiple Discipline Research Projects: Alternative Cropping Systems

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Rationale

The ACS project involves researchers from a number of disciplines including agronomy, entomology, weed science, agrometeorology, pathology, soil science and economics. The life span of the project, anticipated to be 12-18 years, will generate a large amount of data. As a result, management of data associated with the ACS project has been a priority since the project was first initiated. This report is a summary of data management developments associated with this project.

Groupshare Database

The first data management system, implemented in 1996 had the following characteristics:

- A shared data archive system, the archive automatically backed up on a daily basis
- An archive structure that provides various levels of read/write security; all collaborators given read access to all files, but given write access only to personal data folders
- Database format must permit file transfer between programs (word processors, spreadsheets, graphic programs, databases, and statistics packages).
- Data is available anywhere from within the AAFC computer system

Relational Database

In 1999, a relational database was developed to investigate the utility of developing a database application for the ACS project. Microsoft Access was selected and an initial ACS database was developed. Arthropod, agronomy and ag-meteorology data was imported into the database.

Current methods of data management that are based on spreadsheet programs such as Microsoft Excel are becoming increasingly limited in their ability to summarize data. Furthermore, spreadsheets do not have any control over possible errors in data entry/validation and have limited security utilities. Recent advancements in computer hardware and software have 'relational database management' to desktop computers.

A relational database is an application that can create, organize, and edit information. Relational database management systems (RDBMS) allow studies to relate diverse datasets. Data sources include: spreadsheet files, text reports and summaries, graphics/images, statistical output, HTML/ASP, and information from other databases. Databases can output information to any of the input sources. The data is displayed through user-selected views. The user interface includes menus, command buttons, and hypertext links. The interface is developed to help clients navigate within the database. Most relational databases have system programming languages (SQL, VB). The program languages are capable of programming a wide array of applications that are specific to user's requirements. RDBMS use referential integrity to ensure that results are valid within the models of each database, and allow for multiple level security.

Results and Discussion

LTACS Windows NT Groupshare

The data management project was initiated in 1996. The initial design involved development of a Windows NT Groupshare (AAFC - Saskatoon Research Center). The LTACS (Long Term Alternative Cropping Systems) groupshare gransts specific (folder level) read/write permissions. Current groupshare specifications are as follows: Size: 812 MB, Folders: 561, Files: 561 (January 17, 2001).

The format of the folder is as follows:

Annual Activities

- Agmet
- Agronomy
  - Biomass
  - Nutrient Recovery
  - Production-Quality
- Arthropod
- Economics-Energy
  - Balance
  - Inputs
  - Outputs
- Microbial
- Mycorrhizae
- Soil
  - Soil Fertility/Chemical Properties
  - Physical Properties
  - Water
  - Crop Residue
- Treatment Operations & Inputs
  - Harvest
  - In Crop
  - Post Harvest
  - Pre Seed
  - Seed

- Weed
    - Chaff
    - Counts
    - Population Dynamics
- Pathology

LTACS-LS Information

Reports - Posters

- Project Descriptions
- Research Results 1995
- Research Results 1996
- Research Results 1997
- Workshop proceedings 1996
- Site Characterization

Site Characterization

- Biotic
    - Arthropod
    - Crop
    - Microbial
    - Weed
- Soil
    - Soil Fertility/Chemical Properties
    - Physical Properties
    - Crop Residue

One of the objectives of the groupshare project was to provide recommendations for folder structure and file formats. The formats must be uniform and flexible. The data sets should be designed so that data can be transferred into other programs (today and the future).

- Preferred file formats: Excel, Quattro, ASCII (comma or space delimited), or SAS
- Preferred file structure:
    - Each row should be a record
    - Identify rows with
        - Year, date, sample type, owner, plot, treat, var1, var2...
    - 1997 June 10 Pitfall Braun 101
        - If a spreadsheet is used, it is useful to create a README sheet explaining the data
- Preferred folder structure:
- The LS has defined specific folders by Activity and then Study. Users have been assigned write access to specific folders. Within studies, folders with site/trap designations have been defined and users have been assigned write access to specific folders.
- Users can create their own folders at the next layer of the hierarchy. For example, Leeson can create folders below the WEEDS folder and Braun can create folders below the PITFALL TRAP folder.

- It is recommended that users create folders by year. For example Leeson should name folders below weeds by year:
  - Activity 1
    - Weeds
      - 1997
      - 1998
      - 1999
      - 2000
- NOTE - write access will automatically be transferred to succeeding levels of the hierarchy. For example: Thomas and Leeson have been given write access to the WEEDS folder of ACTIVITY 1. Any folders created under WEEDS will have write access automatically transferred to the next level.

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Recommended Changes to Cropping Operations for Second Rotational Cycle

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Tillage

- Use minimum tillage or till 'as required' with high inputs. This change is made to more closely reflect tillage practices used by 'conventional' growers in the area. Tillage to date has followed a more rigid structure that likely exceeded that which growers would normally use.
- With Organic inputs, emphasis will be placed on tillage practices that conserve residues yet facilitate control of weeds.

Compost Application

- Apply compost in the Diversified Annual Perennial, Organic and Reduced input systems at rates based on what would be generated from feed removed and used in an associated feed lot. [Base rate on N content of forage and feed barley removed over past 6 yr cycle minus estimated N removed by feeders = N to be applied]. Apply and incorporate in fall to phase being broken from perennial forage, starting in 2001, and continuing annually thereafter. The use of compost or manure was part of the plan for these treatments, but planed to begin at the end of the first cycle. Compost was chosen over manure, due to the highly variable nature of manure, and greater uniformity of compost.

Perennial Forages

- Eliminate oat companion crop, and seed to alfalfa alone. (Possibly AC Caribou). Could fall seed or seed in early spring. Establishment of perennial forages has been erratic, partially due to inadequate seed bed moisture, and excessive competition with the oat nurse crop. These changes should address both issues.

Organic Canola

- Switch to Oriental mustard (*B. juncea*) and seed early in an attempt to establish the crop ahead of weeds.
- Delayed seeding of canola has resulted in excessively weedy crops in some years, and earlier seeding may allow the crop to establish in advance of weeds. The switch to Oriental mustard also reflects difficulty in marketing canola as an organic crop.

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Fall Rye

- Eliminate use of ethalfluralin in preceding canola crop, and fall mid row band N at a rate to replace 90% of N removed by grain in the preceding canola crop. Elimination of ethalfluralin in the preceding crop should improve establishment, and fall N application should ensure that fertilizer N is available early enough in the growing season to optimize yield.

Lentil Green Manures

- During dry cycles, green manures have depressed succeeding crop yields, due to moisture use by the preceding crop. Green manure lentil was typically seeded in late May. However it is well adapted to early seeding, and earlier seeding would facilitate earlier incorporation. This would allow greater time for recovery of moisture reserves. Seed earlier [late April - early May], so incorporation is earlier, to allow for moisture recovery. In very dry conditions could switch to AC Greenfix Austrian winter pea.

Fungicides

- To date fungicides have not been used extensively in this study, partially from a lack of support to make decisions on their use. Apply fungicides in High and Reduced Input Systems based on recommendations from Gossen, Kutcher and Fernandez.

Sweet Clover Green Manure

- Recent research at Lethbridge indicates that sweet clover residues on the soil surface provide a degree of weed control, conserve moisture and provide erosion protection. In this study sweet clover was previously incorporated, leaving little reside for erosion protection. This practice will be modified to mow and leave residues on the soil surface to conserve moisture and suppress weeds, and provide cover for erosion control. Till only if weeds are a problem. If sweet clover fails, reseed to lentil green manure.

Canola

- Switch to the most productive Liberty tolerant hybrid available in the High and Reduced input systems. This will facilitate moving away from use of ethalfluralin for weed control and some of the associated problems [see note on fall rye]. It may also facilitate study of the impact of herbicide tolerance on soil arthropods.

Weeds

- Need to explore possible option for reducing populations of summer annual weeds (green foxtail, lamb's-quarters, stinkweed, wild buckwheat, redroot pigweed) in the organic production systems (e.g. increasing crop competitiveness).
- Include chaff collection on the list of treatment operations as it may need to be considered in various types of analysis.
- Ensure harvest equipment is cleaned thoroughly between treatments to prevent introduction of volunteer crop seed and spread of weed seed.

Weed Biomass

- Weed biomass will be determined on all crops, [including forages and green manures] based on a modified protocol to be developed by Daniel Ulrich.

Chaff Collection

- Chaff will only be collected and analyzed for weed and crop seeds on the organic inputs diversified annual perennial systems; mustard, wheat and barley. This change is instituted due to the high resource requirements for analyzing chaff, and it's limited impact on weeds in the reduced input systems.

Cultivars

McKenzie wheat	Prima fall rye	Common Yellow blossom sweetclover
Merit barley	CDC Mozart pea	
Norlin flax	AC Caribou alfalfa	
Cutlass Oriental mustard	Indianhead lentil green manure	

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Plans for Second Rotational Cycle

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Sustainability Indices. A.G. Thomas

- To adequately evaluate sustainability of systems, we need to identify indicators of sustainabilty and appropriate ranges of values for each. Some activity has been initiated on this by Gordon Thomas, and this needs to be continued and expanded.

Multivariate Statistical Expertise. A.G. Thomas

- In order to perform integrated analyses of datasets, there is a need for expertise in multivariate expertise. Some expertise is available with Gordon Thomas and Julia Leason, but the expertise may not be available in future.

Meteorological Monitoring. R. Weiss

- The weather station should continue to be operated in a similar fashion to the first rotational cycle. Three changes should be considered:
  - Alter the datalogger program to provide 20 minute values, rather than 24 hour values
  - Purchase a wind sensor
  - The current Campbell Scientific RH sensor requires annual replacement of a chip to ensure proper operation. This sensor/chip is no longer available. A new sensor will need to be purchased in order to continue to collect relative humidity data.

Potential for Wind and Water Erosion. A. Moulin

- Current plans for the study are for measurement of crop residue cover using counts from photographs from two quadrats per plot in the second and sixth phases of the treatments if funds are available. Additional research on bulk density, aggregate size distribution, penetration resistance and soil carbon can be completed with incremental funds.

Soil Arthropods. O. Olfert

- Pest dynamics. Factors that influence crop pests are weather, food supply, habitat and natural enemies. The next cycle will include monitoring of pest populations annually. The information will be made available in a timely manner to the site manager. This information will also be useful to explore the role of farming systems on insect pest population increase or decrease at the end of the next cycle.

- Pitfall Traps. Natural enemies of crop pests (predators and parasites) that demonstrate an adaptation to life in agro-ecosystems are more likely to play a larger role in pest population suppression than those species associated primarily with natural ecosystems. Unless additional funding is obtained, it is not likely that pitfall traps will be implemented in the interim years but only at the end of the next cycle. It is anticipated that Collembola, Arachnida, Coleoptera, Homoptera, Hymenoptera, Diptera and Hemiptera will be monitored (abundance and species richness) in relation to input and rotation.

Mycorrhizal Fungi. S.M. Boyetchko

- Our plans for the second rotational cycle are to understand the diversity and abundance of AMF under the different cropping systems.
- Specifically, our plans are:
  - Determination of the relative abundance of AMF propagules under selective crops (e.g. wheat) and cropping systems every year.
  - Determination of the percentage AMF-colonized root length of crops every year. In addition, AMF colonization of weed species in some specific rotations including wheat and barley will be assessed. There will be a focus on specific treatments to get a better evaluation on the changes in relative AMF abundance/functioning and spatial/temporal changes.
  - Site characterization of AMF populations at the beginning and end of the six year cycle
  - Identification of AMF species (using DNA probes)
  - Complete site characterization (spatial and temporal changes)
  - Correlation analysis of microbial parameters with yield, disease index and weed strength

Disease Monitoring. R. Kutcher

- Continued monitoring of disease will continue in a similar fashion as occurred in the last half of the first six year rotation cycle (section D). Emphasis will be placed on establishing baseline measurements at the beginning of the second cycle (2001), and end of cycle (2006) with strategic timing of interim disease surveys that coincide with climatic conditions conducive to the initiation and spread of disease. Careful monitoring of disease thresholds at growth stages where fungicides would be most beneficial will be implemented to ensure fungicides are applied in a timely manner where required.

Cereal Disease Identification. M. Fernandez.

- Based on the results obtained in 1997-2000, we conclude that a detailed assessment of leaf spotting pathogen populations continue being done in cereal varieties that are susceptible to an array of pathogens and where we might be able to identify a treatment and/or environmental effect.
- We also propose that, in addition to continuing with the identification of leaf spotting pathogens, fungal isolations from infected roots be done to determine treatment effects on root rotting pathogen populations.

Weed Biomass. D. Ulrich

- Legitimate comparisons among systems requires the measurement of weed biomass in forage and green manure phases in order to provide a complete picture of weed biomass levels in each system. The logical time for conducting weed biomass sampling would be just prior to incorporation in the green manure phases and prior to cutting in the forage phases. This timing would capture the most mature weeds and would be a better predictor of plants producing viable weed seeds similar to the sampling protocol used in annual crops where sampling takes place near the time of swathing.
- To better account for weed biomass variability that may exist within a plot it is recommended that the

sample areas be reduced from 1.0 m^2 to 0.5 m^2 but that the number of sampling sites be increased from 2 to 4. Sampling in diagonal corners of the plots could be retained with an additional 2 sites spaced evenly apart on a diagonal line between the corners. The additional 2 sites could be accessed by pacing 20 meters from the end along the side of the plot and 4 metres in from the edge. This procedure would minimize crop damage and still provide a centre path for harvest yields to be obtained. A conscious effort should also be made to avoid repeated sampling in the exact same area to avoid a potential bias of the results caused by above ground biomass removal. This could be done by establishing a zone around a specific sampling site where the actual sampling site would be rotated over a number of years.

Soil Physical and Chemical Properties. R. Lemke

- Soil sampling and analysis will be conducted in the final year (year 12) of the second cropping cycle following the protocols described above. Preliminary carbon and nitrogen budgets will be developed using data collected during the first cycle. To the greatest extent possible, any uncertainties identified will be addressed during the second cropping cycle in order to refine these budgets. Lastly, if resources allow, greenhouse gas sampling (N_2O and CH_4) will be added to the soil quality assessment protocols during years 4,5 & 6 of the second cycle.

Soil Respiration and Enzyme Activity. V.O. Biederbeck.

- At the end of the second cycle, the same plots should again be sampled for the same depths to determine the soil microbial parameters measured.

Colonization of Non-egumes. K.G. Hanson.

- The Scott ACS allows for a unique research opportunity to be undertaken relating to the evaluation of endophytic rhizobia. Studies on the effect of crop diversity, including legume frequency, and production systems on the development of endophytic rhizobia/non-legume associations will be possible at this site. It has been suggested that endophytic rhizobia may boost production in organic systems more than in conventional production systems due to higher frequency of legumes and absence of synthetic fertilizers and other agrichemicals.
- A preliminary study will be done in the second year of the second rotational cycle of the Scott ACS. Selected rotations with low and high frequency of legumes will be sampled and endophytic rhizobia enumerated. A more extensive evaluation of rhizobial endophytes at the end of the second cycle will be conducted only if satisfactory results are obtained in this preliminary study.

Data Storage. R. Weiss

- The current ACS database has grown to exceed the limits of the software (Microsoft Access) and other software needs to be investigated to manage it. The only way to continue with Access would be to modify the database to decrease the size, clients, or objects. We can be confident that data accumulation will continue to increase, and communication of information will continue to exploit Intranet/Internet technology to enhance data exchange.
- The recommended solution would be to upload the database to SQL Server and use Microsoft Visual Basic (VB) as the front end client interface. This solution would allow for a robust system that is scalable and can be published on a web site. These systems are considered to be more cost effective than file-server applications. Microsoft SQL Server provides a system that allows upsizing of Access database with minimal effort while realizing significant benefits. Visual Basic would be used for not only development of a User Interface for database development, but also a web development tool.
- This will involve purchasing the software (SQL Server and Visual Basic Upload), uploading the

database into SQL Server, developing the database front end with VB, testing, distributing the agronomy, arthropod, ag-meteorology portion of the database to study participants, adding data associated with other disciplines, distributing the complete database, and publishing the database on the intra/internet.

Alternative Cropping Systems

ACS Long-Term Agro-Ecosystem Research for the Canadian Prairie Ecozone
1994 - 2012
Research Farm
Scott, Saskatchewan

Recommendations on Gaps, Shortfalls or Missed Opportunities

S. A. Brandt

Agriculture and Agri-Food Canada, Scott Research Farm, Scott, SK

Meteorological. R. Weiss

- The datalogger is currently programmed to record values every 20 minutes and these values are used to calculate 24 hour summaries. The current data set is capable of providing daily, monthly and seasonal summaries. There may be some need for hourly or 20 minute recording. The weather station does not currently have a wind sensor to record wind speed and direction. Temperature and wind data, with 20 minute recording, would be useful for agronomy (spray application history), entomology (wheat midge developmental and oviposition models) or pathology (define periods (hourly) when conditions are suitable for pathogen development), It may be useful to consider modification of the datalogger program to have recordings every 10 seconds and then calculate 20 minute summaries.

Cropping and Soil Components. S.A. Brandt

- To date, protein contents of grain and forage have been determined, but grading has not been done. Training technical staff at Scott to facilitate 'on site' grading of grains, including archived samples will be undertaken. This will provide additional information in support of economic analyses, and will provide additional information on quality of production.
- To facilitate interpretation of data, particularly on crop production and pests, more extensive information on crop stands is required. Digital imagery as a means of measuring crop stands was suggested as a possible way to accomplish this, as it could provide information on not only plant numbers, but also crop and weed canopies relative to one another. An attempt will be made to develop a standardized protocol using digital photos to be used to determine the relative proportions crop and weeds in the canopy. This would not be instituted in 2001.

Potential for wind and water erosion. A. Moulin

- Amounts of residue cover required for erosion control vary depending on soil texture. Levels of crop residue were low at the beginning of this study, and crop residue cover should be measured in future years to determine potential for erosion. Crop residue levels may not reflect the system's potential for soil erosion until two rotation cycles are complete. Measurement of crop residue in each year of the second cycle is recommended.
- Changes in soil properties such as organic matter can affect soil physical properties such as aggregate size distribution, bulk density and penetration resistance. Inverse relationship between bulk density

and organic matter is often cited in the literature. (Gajda et al 2001). This change is attributed to stratification of soil carbon and nitrogen in the profile, where total C and N in the 0-5 cm depth are higher in the reduced tillage systems than in conventional tillage. Differences in the 5-10 cm and 10-15 cm depths are often not significant (Grant and Lafond 1993, 1994). The study presents an opportunity, at the end of the second cycle, to determine the relationship with soil physical properties as affected by stratification of organic matter. Furthermore, this information can be used to develop an index of tilth or sustainability.

Gajda, A. M.; Doran, J. W.; Kettler, T. A.; Wienhod, B. J.; Pikul J.L., and Cambardella, C. A. Soil quality evaluations of alternative and conventional management systems in the Great Plains. Lal, R.; Kimble, J. M.; Follett, R. F., and Stewart, B. A., eds. Assessment methods for soil carbon. Boca Raton: Lewis Publishers; 2001; pp. 381-400

Grant, C. A. and Lafond, G. P. The effects of tillage systems and crop rotations on soil chemical properties of a black chernozemic soil. Canadian Journal of Soil Science. 1994 Aug; 74(3):301-306; ISSN: 0008-4271

Soil Arthropods. O. Olfert

- Having attended two international workshops related to cropping system studies, the authours have the sense that we are monitoring appropriately. Arthropods, including insects, spiders and mites, are integral to crop loss and to soil health, in that they include both beneficial and pest species. The one animal group commonly monitored in other studies, that is not assessed here, are earthworms. The assessment of earthworms is being considered in this next rotational cycle
- Some estimate of invertebrate biomass is required, as an indicator of treatment effects.

Mycorrhizal Fungi. S.M. Boyetchko

- AMF biodiversity
- Detailed aspects of AMF functioning
- Fertilizer use efficiency - influence of AMF on nutrient uptake under different input (fertilizer) levels
- Impact of AMF on suppression of soil-borne diseases
- Impact of AMF on weed-crop competition

Disease Monitoring. R. Kutcher

- Although data collection in the first ½ of the first year cycle was limited, the impact of input level decisions and cropping diversities was most likely to occur in the second half of the rotation cycle. Results of more intensive disease surveys in the last half of the first year rotation cycle support that theory, suggesting disease monitoring was adequate to evaluate system level affects on disease and their impact on yields.
- Dan Ulrich to continue rating disease identification and rating on grain crops on an annual basis, with identification support from Gossen, Kutcher and Fernandez. Treatment structure is designed to minimimize disease. Where conditions are favorable for high levels of infection, consideration will be given to expanding activities.

Weed Communities. A.G. Thomas

- Inconsistent number of yearly weed assessments. No pre-treatment counts in 1995. No spring counts in 1995 and 1996. Post-harvest counts were not done in 1999 and 2000.
- Year-to-year variation in the date the treatments were counted relative to the date of operations is too large and needs to be reduced.
- Chaff samples from 1999 and 2000 have not yet been processed because separating weed seeds from

the chaff is a very time-consuming and costly.

Weed Biomass. D. Ulrich

- By only collecting weed biomass within annual crops results fail to provide a complete picture of weed biomass within systems containing forage or green manure phases.
- Weed biomass sampling was primarily restricted to the corners of the plot which raises the question are we really obtaining an accurate measure of weed biomass as it exists in the rest of the plot given the variability in weed growth that can occur. Added to that is the reality that an assessment of what is representative of the entire plot is very difficult if not impossible to make when the canopy is closed. Repeated sampling in the same general area also raises a concern that removal of above ground biomass year after year may affect results.

Weed Population Dynamics. A.G. Thomas

- Information on the growth and reproduction of stinkweed and lamb's-quarters was collected during the first cycle. This information was use to calculate the efficiency of chaff collection. Sufficient data were collected for these species. The persistence of volunteer canola and wheat is an important issue that could be studied using similar methods during the second cycle. Data on plant size , biomass and seed production should be collected if volunteer densities are high enough to warrant sampling.

Soil Physical and Chemical Characteristics. R. Lemke

- Total above ground biomass of green manure is required to accurately calculate C & N budgets. In addition, root C & N inputs are currently estimated from data provided by other studies. If resources allow, actual measures of root C & N from selected phases of treatments in this study would be of considerable value. Lastly, quantification of N2O and CH4 budgets are needed to complete environmental impact assessments.

Soil Respiration and Enzyme Activity. V.O. Biederbeck.

- Endophytic rhizobia may play a very important role in the benefits of legumes to a crop rotation especially in the organic production system. Endophytes are described as bacteria that can be isolated from surface-disinfected plant tissue and do not visibly harm the plant. Thus endophytic rhizobia are those found inside plant tissue.
- Many studies have now shown endophytic rhizobia are present in several other non-legume crops such as spring wheat and barley, maize and canola. The legumes in rotation with these crops can vary as well from clovers to beans, peas and lentils. The benefits related to the rhizobial endophytes may be due to one or more of several modes of action. Rhizobia have been found to solubilize C_a-bound, inorganic phosphate and increase uptake of other micro and macronutrients, increase N-use efficiency, produce phytohormones, siderophores and HCN, and antagonize plant pathogenic fungi.
- Consideration should be given to utilizing the Scott ACS undertake research relating to the evaluation of endophytic rhizobia..

Reference Ecosystems. V.O. Biederbeck

- In view of the failures and difficulties experienced during the first cycle of rotations with regard to successful establishment of perennial forages in the high diversity (DAP) system, it would be very useful for a meaningful interpretation and assessment of cropping diversity effects on soil biological quality to sample and analyze surface soil from some nearby ecosystems with perennial and mixed vegetation cover such as the 'virgin' prairie site, the 'old' prairie site, the 30 yr old brome-alfalfa site and some others.